Def Sci J, Vol 38, No. 3, July 1988, pp 315-320

UV Laser Fluorosensor for Remote Sensing

V.N. Saxena
Institute of Armament Technology, Pune–411 025

ABSTRACT

Several substances both organic and inorganic, when excited by a low wavelength radiation, fluoresce; the fluorescence in the longer wavelength region is generally characteristic of the substances so irradiated and to some extent of the wavelength of the exciting radiation. Thus, the spectral analysis of this fluorescence can be used to detect, monitor and even quantify the presence of matter on which the exciting radiations impinge. The rate of decay of the fluorescence alongwith a spectral and temporal return signals, such as from oil spills, have been described in this paper as also the functioning of an airborne laser fluorosensor using a 1 MW pulsed nitrogen laser.

1. INTRODUCTION

During the last decade, fluorescence spectroscopy has been used extensively in a wide range of disciplines as both a quantitative and qualitative analytical technique[1–5]. Many environmental city pollutants and oil spills in and around oceans have characteristic fluorescence properties. These can now be detected easily and identified from a distance by a laser fluorosensor (LF) mounted on an aircraft or a helicopter. The LF detects trace amounts of fluorescent matter using an ultraviolet pulsed nitrogen laser. A narrow beam of laser is emitted geometrically coaxial with the receiver optics, which collects the fluorescent light from the target. The fluorescent visible flux, at wavelength longer than the exciting laser wavelength, is detected by an spectrum analyser in synchronisation with the back scattered radiation pulse, so that the LF can operate in full day light also. The spectral emission data is reflected in a 16 channel bar chart while the temporal information is indicated by the decay time values. Normally, LF works at an altitude of 330 m during day and 660 m at night. The

Received 26 November 1985; revised 21 March 1988

remote sensing and assessment of chlorophyll concentrations as an index of quality of water is presently being studied by Rayner and O'Nell[6].

2. EXPERIMENTAL SET UP

LF is an active electro-optical remote sensor for use from an airborne platform for detection, classification and quantification of trace amounts of fluorescent material. Laboratory studies have resulted in a comprehensive catalogue of fluorescent visible flux return as a sort of an atlas. A 1 MW pulsed nitrogen laser at wavelength of 337.1 nm, 4 n sec pulse width, with a repetition rate of 100 Hz has been extensively used, although the optimum excitation wavelength varies, depending upon the pollutant to be monitored. Other lasers e.g., quadrupled and doubled *Nd : YAG* laser (266 and 532 nm), flash-pumped dye lasers (400 – 500 nm), and *He–Cd* laser (442 nm) have also been used. Since fluorescence is the emission of visible light from photo-excited molecules, the exciting wavelength must be preferably in the violet or UV region. The basic concept of an LF is shown in Fig. 1. Although both pulsed and cw lasers heve been used in the LF system, there is an advantage in the pulsed one for, one can employ gating techniques in the detector. This leads to a significant attenuation of the background radiation and also prevents overloading of the detector system. The background radiations finding way into the receiver unit, are primarily due to scattering of the ambient light by the ground surface and the ingredients of the atmosphere. Since their intensities are quite comparable, it becomes difficult to employ a non-gated pulsed LF or cw system during the night time. In a pulsed-lasergated detection system, the detector is first gated for the duration of the return fluorescence signal. This signal is also of a pulsed nature because the fluorescence decay times are

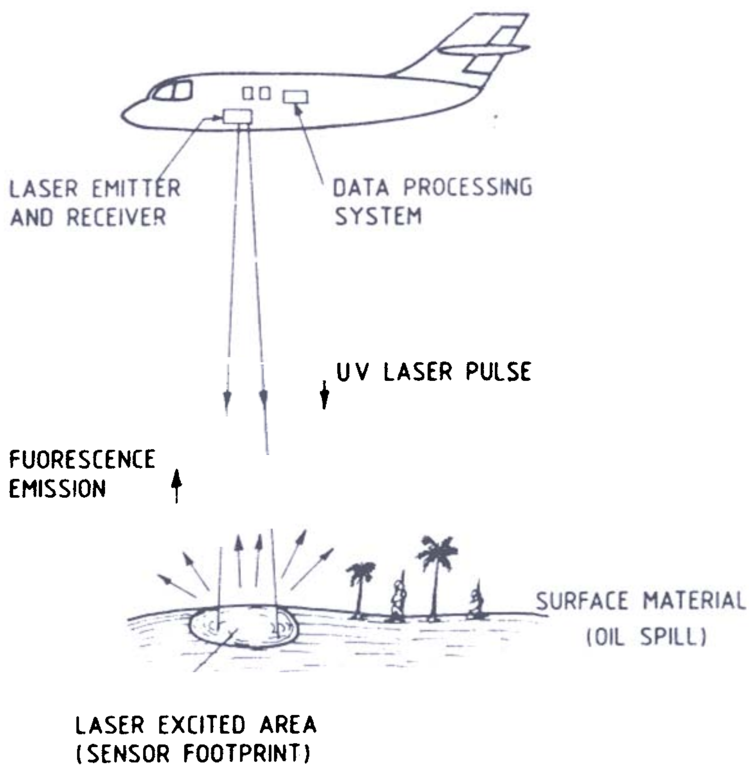

Figure   Principle of airborne laser fluorosensing system normally less than 30 n sec. Thereafter the detector is gated again between laser pulses, giving a measure of the background which can be deducted from the intensity of the signal pulse. If the gate width is 50 n sec with laser repetition rate 100 Hz, the reduction in background is 2×10^5 times; by using this technique.

If the laser repetition rate is too slow to provide suitable resolution on the ground, the benefits of pulsed system are outweighed. If the speed of the aircraft is, let us say, 320 km/h, a rate of 100 Hz provides a resolution of approximately 1 m on the ground. In most of the LF operations a resolution of 10 m is more than sufficient. However, using helicopters or some other stationary platform, lower rates can be employed. The resolution or rather the resolving power is found to be directly proportional to the repetition rate.

In order to fully exploit the advantage of background noise reduction, the laser pulse width should be less than the fluorescence life time of the specimen under detection and characterisation. Naturally smallest gate-width is desirable, if one has to measure the decay time very accurately. It also gives additional information for the target[1]. The fluorescence spectra of the fluorescing oils in the ocean can distinguish between light refined oil e.g. diesel oil, crude and heavy refined oil (bunker fuel[7]). The fluorescence signal strength depends on the strength of the laser inducing it. In the shot-noise limit, the signal to noise ratio is proportional to the square of the power. The strength of the fluorescence return signal depends on the power of the laser beam. It is, therefore, essential that the exciting beam should be high-peak-power UV laser. In the final analysis, it turn out that the LF must be compact, light weight and self-sufficient so as to be easily carried in a flying aircraft. Barringer Research of Canada has developed such an airborne LF which can be used in full daylight from a flying altitude of 15000 feet. This has been successfully tested for marine pollution monitoring[8]. When oil is floating on the ocean surface, it is effected by wind, bacterial activity and sunlight (called weathering for LF purpose). It has been shown by Rayner[9] et al. that the fluorescence return is not significantly affected for the normally encountered range of sea-states and weathering in deep water.

An LF system based on nitrogen laser consists of a sensor head housing the laser and a telescope field-stopped on just the area of the ground illuminated by the laser (sensor foot-print). There is a wavelength selector to cut off the reflected laser light. It also contains receiver optics, electronic sub-systems, video-display, micro-computer, buffer memory, tape-deck and LF remote control module. The other package has power supply, vacuum pump and nitrogen for the laser unit. Other filters can be used to determine the detector bandpass.

In the case of a pulsed-laser-gated detector operations, the gating electronics must be triggered by the out-going laser and an appropriate delay accounted for so as to allow the laser to reach the target (foot-print) and the visible fluorescent flux to return before the gating photo-multiplier tube is gated open. This can also be adjusted with the help of the aircraft's altimeter. The delay can be inferred from the starting time of the earlier pulse as well. If the anode signal is gated, the detector gets over-loaded. To avoid this, it is preferred to gate the tube itself. One has two choices; either to use a special type of tube having a built-in gating electrode or introduce a method of pulsing an ordinary tube. By using a dual-channel boxcar integrator with arrangements for signal routing and gating, the pulsed operation of the signal processor becomes smooth and efficient. It automatically performs the required background subtraction and integrates the appropriate number of pulses.

The output signals of spectrograph are sliced and carried by optical fibres to an array of photomultipliers or image intensifier tubes. For detecting oil in the ocean spectral resolutions of 20 nm in the 350–700 nm range are required and attained[2]. In conjunction with the spectrograph, optical fibres and phototubes, it is advisiable to use a micro-processor-based date acquisition system to display, control and store the information. A pollutant detection alarm too can be incorporated. A rapidly scanning mirror directs the sensor foot-print, so that a fluorescence image of the terrain under a flying aircraft is formed. The Canada Centre for Remote Sensing (CCRS) have used two LF systems to detect oil spills and as an off shoot of this, they have used it for oil exploration. Natural oil and gas seepages normally do occur and are indications of under-sea hydrocarbon deposits. An LF system offers an opportunity for large scale aerial surveys for oil spills. Fluorescence spectra of three types of oils are shown in Fig. 2. It is based on their respective densities, by Rayner and O'nell[6]. When excited at 337 nm, the crude oil shows a broad spectral profile with a peak at λ max between 480 and 570 nm and quantum efficiency η max (defined as the ratio of the number

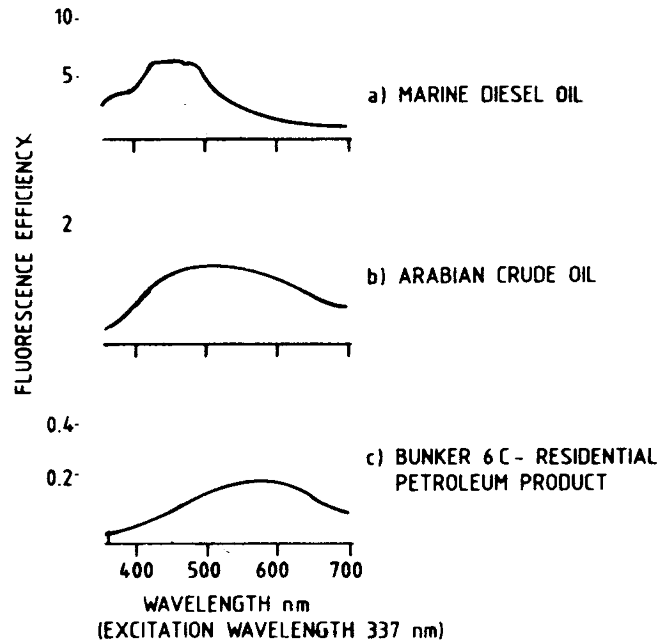

Figure 2. Fluorescence spectra of oils.

of visible photons produced and the number of UV photons incident/absorbed) between 4×10^{-5} and 4×10^{-4} nm^{-1} at λ max. Similarly furance and marine diesel oils indicate a little structural emission with λ max around 455 nm and η max between 2.4×10^{-4} and 6×10^{-4} nm^{-1}. λ max and η max values for residential petroleum product are between 525 and 600 nm and 1×10^{-5} and 6×10^{-5} nm^{-1} respectively.

The fluorescence decay times are shown to be highly characteristic of the oils[9], but for this, one has to have an LF system with a high signal to noise ratio. Almost all oils show longer decay times in the red than blue of the spectrum. At a particular wavelength, heavier the oil stronger the decay. This helps distinguishing between oil and targets e.g., dyes which do not exhibit decay time wavelength dependence. If there is no oil on the surface of water, the Raman scattering by water is quite strong due to deeper penetration of the laser beam. However, with the presence of oil, the Raman signal is suppressed. Further discrimination amongst the varieties of oils can be achieved by devoting an LF channel to Raman wavelength.

3. CONCLUSION

Remarkable success has been attained in the identification and classification of oil spills particularly in the ocean to meet future energy needs of our fast growing civilisation and in the distribution of chlorophyll in water[4]. Since chlorophyll in green plants fluoresces in the wavelength range of 650–750 nm, the best excitation can be had by a laser in the 400–500 nm range. As such, the flash lamp pumped dye lasers with low repetition rate and operated by helicopter will serve the purpose[10]. Though chlorophyll is not a pollutant, its concentration is an indication of various environmental conditions. For instance, in the assessment of plant stresses due to lack of nutrients, reaction to pollutants and parasites or known outbreaks of diseases.

4. FUTURE DEVELOPMENTS

Now high power lasers are available, as also the facilities provided by satellites and space-laboratories, LF can be used for mapping of surface deposits of ores for instance, Uranium and in identification of the species of forest trees and agricultural

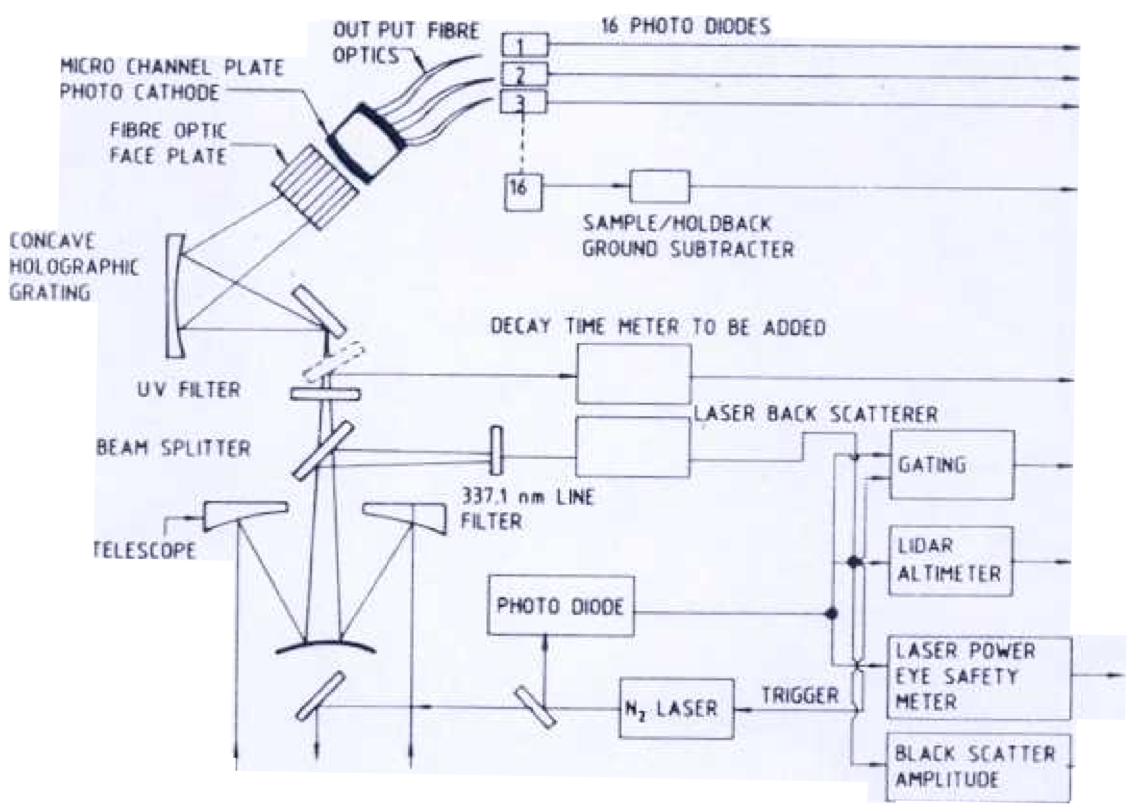

Figure 3 Schematic diagram of LF with only major electrooptic components

crops, for hydrological studies, search and rescue missions. Having prior information about the fluorescent characteristics of the enemy concentration or installation etc., LF can be used for inumerable military purposes as well.

Several environment-monitoring roles such as aromatic solvents used in coal-liquifaction plant, pulp-mill effluent, coal-mine tailings, biodegradable dyes (needed for photographic surveys), insecticide spraying operations etc. can be performed by using suitable LF[11]. Often the pesticides are mixed with oils, which maintain the fluorescence properties of the oils; such that the quantity of the insecticide is constantly monitored. Sometimes fluorescence dyes are added. For such types of monitoring it is advised to use shorter wavelength laser, possibly excimer laser (240 nm). By reducing the wavelength the LF provides more resolving power and sensitivity.

Since UV is harmful to the eyes, its constant monitoring is required; such that it remains within the safety limits and yet performs well its required function. This is advised to be done by laser power meter and altimeter. Fig. 3 shows the schematic diagram indicating the major electro-optic components; laser support, power supply, N_2 supply, vacuum pump, microprocessor based data acquisition system. Video display in real time for operator-machine have not been shown.

REFERENCES

Rayner, D.M.& Szabe, A.G., *Appl. Opt.*, **17** (1978), 1624.

2 Sato, T., Suzuki, Y., Kashiwagl, H., Manji, M. & Kakui Y *Appl. Opt* **17** (1978), 3798.

3 Bristow, M *Remote Sensing Environ* **7** 1978) 105

4 Messures, R.M Laser Remote Sensing Wiley, N.Y.), 1984

5 Lillesand, T.M. & Kiefer, R.W., Remote Sensing and Image Interpretation second Ed. 1987.

6 Rayner, D.M. & O'Nell, R.A., *Optics News*; Summer 1979.

7 Fantasia, J.F. & Hard, T.M., DOT Transportation System Centre, (U.S. Coast Guard Report TSC-USGC-71-7), 1971.

8 Davies, J.H., O'Neil, R. & Dick, R., Barringer Research Ltd., Presentation at the 71st Annual Meeting of the Air-pollution Control Association, Houston, Taxas, USA. June 25–30, 1978.

9 Rayner, D.M., Lee, M. & Szabe, A.G., *Appl. Opt.*, **17** (September 1978), 2730.

10 Brown, C.A., J.P., et al., Proc. of Fourth Conference on Sensing Environmental Pollutants. (American Chemical Society, Washington, D.C.), 1978, p. 782.

Chappelle, E.W., et al Laser Induyed Fluorescence of Green Plants, *Appl. Opt.*, **24** (1985), 74–80.