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A Fluorescence LIDAR for Land and Sea Remote Sensing

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Abstract

Researches on the application of fluorescence LIDARs to the remote-sensing of land and sea surfaces were carried out at IROE and IEQ of the National Research Council (CNR) during last years.
The researches involved the use of laboratory and computer simulations and they were mainly devoted to the selection of laser sources, to the detection and characterization of oil spills, and to the analysis of vegetation stresses. As a result a prototype of fluorescence LIDAR was designed and built with a particular attention to the problems connected with the operation on board of trucks, ships, and aircrafts. The system is therefore a rugged, light-weight, small-dimension one, having a low power consumption.
The LIDAR was called F-LIDAR IROE-2. It is able to record high-resolution fluorescence spectra and most of the data-processing can be done on board of the moving platform.

Introduction

Fluorescence emission spectra of natural and human-made objects are strictly related to their chemical-physical composition, and therefore they are suitable as a signature of the observed object.
In living structure case the fluorescence emission depends on the biological activity too and can give information on the knowledge of the living matter.
A remote-sensor based on the detection of the fluorescence emission spectra of the targets is a very attractive one for the monitoring of the environment. The potential application of such a sensor can range from the detection of sea pollution to the analysis of phytoplancton and vegetation.
The fluorescence LIDAR uses a pulsed laser source which irradiates the target, then a receiving telescope collects the backscattered radiation, and finally a detection system makes a spectroscopical analysis of the collected radiation. By means of an accurate selection of the laser wavelength and of the detected fluorescence bands, it is possible to distinguish the specific constituents of the target.
Fluorescence LIDARs have been used by different authors for the detection of oil spills, phytoplancton, and other substances in the sea[1], and of vegetation on the earth surface[2]. These researches evidentiated the need of a new fluorescence LIDAR having a high spectral resolution, and the selection of different excitation wavelengths. From the technological point of view, it has to be light weight, small-dimension one, and to have a low power consumption, in order to allow the in field operation from moving platforms.
This LIDAR project had the name of F-LIDAR IROE-2.

Synthesis on laboratory researches and results

At IROE and IEQ institutes, laboratory experiments on fluorescence LIDAR for environmental application began in 1981. The researches were carried out in order to evaluate, in controlled conditions, the operational limits of fluorescence LIDARs . The attention was focused on the detection and characterization of plants[3] and on sea-pollutants, like oil spills[4,5,6].
The laboratory setup mainly consists of a laser source which irradiates the sample, a receiving optics which collects the radiation emitted from the target, a 250 mm focal length polychromator with different gratings (i.e. different wavelength bands with different spectral resolution), and an optical multichannel analyzer, PAR-OMA 2, for the real time recording of the spectra.
This experimental system simulates a fluorescence lidar, but it is quite easy to perform passive remote-sensing by substituting the laser source with a lamp (which is a broadband, incoherent source) and then achieving reflectance spectra.
In a LIDAR remote-sensing application, vegetation analysis is mainly based on chlorophyll fluorescence detection[7,8,9,10], because chlorophyll is present in all vegetation species. Moreover, since chlorophyll is mainly responsible in the photosynthetic process of living plants, by in vivo measurements of fluorescence and reflectance spectra, it is reasonable to expect information both on species and vegetation stress.

The fluorescence spectrum of chlorophyll in vivo has a narrow band at 685 nm and a broad band at 740 nm. Fluorescence spectra of living plants were detected with a He-Ne cw and a Rhodamine 6G pulsed dye laser excitation. The spectra were obtained in different light conditions, and with plants in different water stress levels.
The results of these experiments showed that the exposition to cw excitation changes the spectral behaviour, while the phenomenon is practically not observable with the pulsed excitation. Moreover background light level and water stress produce variations on the fluorescence detected spectra. For plants in different water stress conditions but with the same laser excitation and the same background level, a differential fluorescence technique is a good tool for water stress detection[11].
Reflectance spectra were also performed, showing the possibility to detect some vegetation diseases and senescence by means of differential reflectance techniques[3,10].
Laser induced fluorescence and water Raman signals are suitable in sea-pollution remote-sensing. Oil spills are characterized by the film thickness and the oil type.These parameters can be detected by a fluorescence LIDAR: the thickness by means of both fluorescence intensity and depression of the water Raman signal, the oil type by means a proper processing of the fluorescence spectrum.
The same experimental setup was used for the study of LIDAR fluorosensing of oil films on sea water. As a first step, the potential of different laser wavelengths was evaluated[4]. Three different lasing gases, N2, KrF, and XeCl were used in a TEA laser, while a fourth wavelength was obtained from a dye laser, stilb.3, pumped by the TEA laser itself. Different oil samples (some of them coming from the European Community ARCHIMEDES 1 and 2 experiments[12]) were tested with film thicknesses ranging from 1 mm to 0.01 um on a water substrate.
Oil absorption has a quite typical spectral behaviour; it drastically increases in the near ultraviolet (UV) and generally emmision spectrum shows a peak in the blue region of the spectrum, at about 450 nm[4]. Although the fluorescence quantum yield is much higher at longer wavelengths, the overall efficiency for low thickness films appears to increase by using UV light. This is due to the greater absorption of oils in this spectral region. The best choice seems to be the XeCl excimer laser emission at 308 nm.
Two methods were investigated for the teledetection of film thickness, based on oil fluorescence and water Raman scattering. Oil fluorescence signal decreases as the thickness decreases, while the opposite happens with the water Raman signal. Both the techniques were tested in laboratory, and a good agreement was found between prebuilt film thickness and detected ones[5,6].
Computer simulations were also done in order to identify the oil in the spill. Since the fluorescence spectra of different oil samples are very similar at the same excitation wavelength[4], distinction is difficult, but it is possible by means of cross-correlation techniques. This technique was tested with the fluorescence spectra of 60 different oil samples,belonging to three classes (crude, heavy, and light) and the identification of the class by means of the shift of the cross-correlation maximum was shown.
The same spectra were computer processed in order to test the potential of the differential fluorescence technique in oil identification. This technique is based on the use of a computer selected set of fluorescence wavelengths. By using only two wavelengths this technique has the same power of the above-mentioned cross-correlation technique, while there are some indications that the use of more wavelengths allows the differentiation inside the class[11].

The F-LIDAR IROE-2

The "ideal" fluorescence LIDAR is a LIDAR which:
- allows the real-time detection of the fluorescence signals in a wide spectral range with a high resolution;
- can operate from UV to extended visible (EX-VIS);
- is suitable also for Raman and differential reflectance remote sensing;
- has a light weight, low power consumption, and a compact configuration;
- can be operated by non-scientific people.

The F-LIDAR IROE-2 is a monostatic coaxial one, and it was designed as a multiporpose fluorescence LIDAR devoted to the remote sensing of land and sea from moving platforms, like aircrafts, ships, or trucks. Its block dyagram is shown on fig. 1.
The laser source is a XeCl excimer laser which can optically pump a dye laser, as suggested by the laboratory experiments. In this way the laser system gives the appropriate wavelength for the excitation of different targets. The wavelengths range from the near UV, for thin oil film detection, to the red, for chlorophyll excitation.
Problems arise in designing the laser source, since it has to operate on a moving platform. Requirements are: high laser power, low power consumption (i.e. high efficiency), and compactness with light weight. Both the excimer and the dye laser were expressely designed for this fluorescence LIDAR. The excimer laser cell is a PVDF tube, 10 cm in diameter and 60 cm long. The excitation is obtained with a high voltage TEA discharge between two electrodes, specifically computer designed for having a narrow discharge volume. The electrical circuit is a charge transfer one, with the secondary capacitors placed inside the gas cell. The preionization is realized with an automatic circuit using the internal capacitors, in order to achieve high efficiency and rudgeness. As a result an energy of 80

mJ/pulse with 15 nsec of pulse-width is obtained; the overall efficiency is about 1% . A sealed spark-gap is used as circuit-switch, because it does not require any power consumption with respect to thyratrons. This is the best compromise between the over-mentioned requirements of high efficiency and compactness.

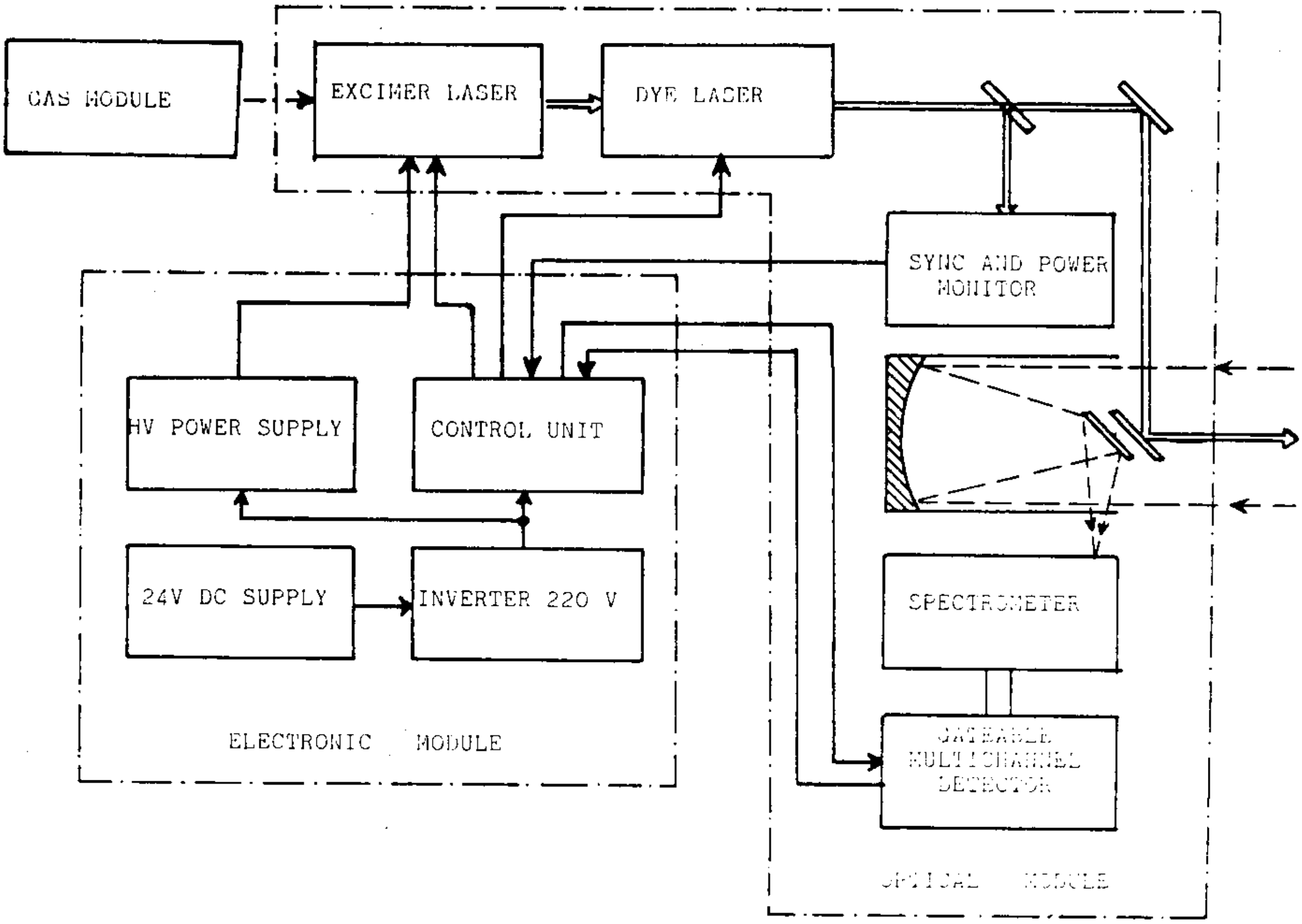

Figure 1

The input optics is a 250 mm dyameter Newtonian telescope which has in its focus the input slit of a 275 mm focal-length grating-spectrometer. This arrangement is an advantageous one with respect to separate channel operation using interference filters.
The spectrometer has three different gratings which can be changed during the measurement in order to achieve the required spectral range and its consequent resolution.
The detection unit is composed by a complete OMA 3 system by PAR, using a gateable intensified head with 512 elements CCD array (mod. 1420 B).
The fluorescence spectra are acquired each laser shot; immediately after the laser pulse, a background spectrum is acquired and simultaneously subtracted from the fluorescence one.
The corrected fluorescence spectra are therefore recorded shot by shot on the hard-disk of the OMA 3 and then they can be transferred on the flexible diskette unit contained in the OMA 3 Console.
The OMA 3 can also operate with a reduced number of channels. This permits to simulate the use of interferential filters and therefore to test in field the above-mentioned laboratory results of the differential fluorescence technique.
An interesting facility of this system is the possibility to operate as a passive remote-sensor for the detection of reflectance spectra, by simply switching off the laser source. It will also be possible to acquire passive remote-sensed data between each laser shot time interval, by a proper adjustement of the gating time of the intensifier.
The system is completed with a standard color TV camera whose images are used as a reference for target identification.

A rough view of the system is shown on fig.2. The maximum height is that of the telescope which is 105 cm and the maximum length is 138 cm.

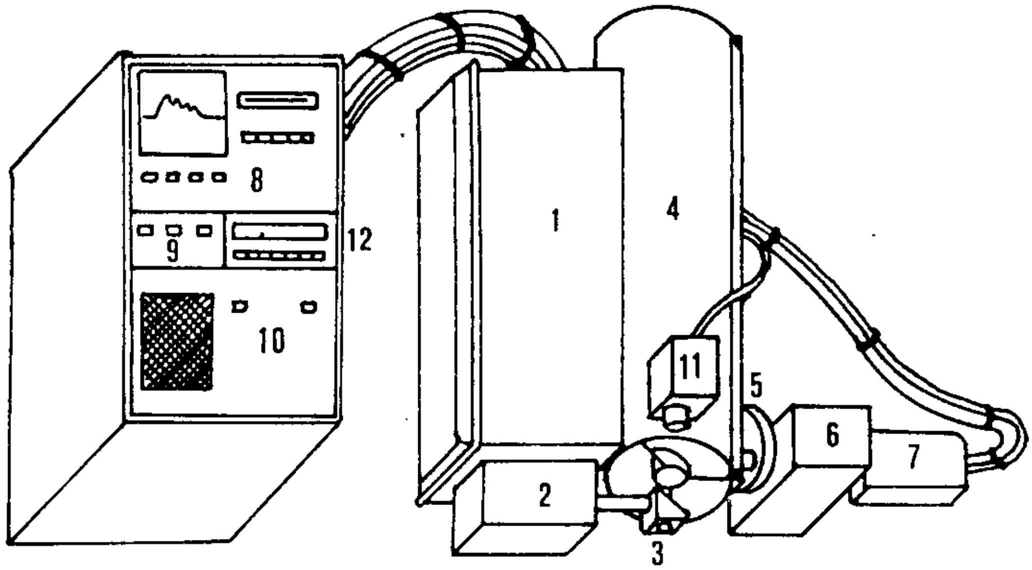

Figure 2: F-LIDAR IROE 2 view. 1.Excimer laser; 2.Dye laser; 3.Laser beam deflecting mirror; 4.Telescope; 5.Filter-holder; 6.Spectrometer; 7.OMA-3 Detector; 8.OMA-3 Console; 9.Pulser; 10.Cooler; 11.TV Color Camera; 12.Video-recorder.

The system requires 900 VA of electrical power and can be operated with 28 V DC line (normally available on aircrafts) or with 24 V DC rechargeable batteries. The overall weight is about 160 Kg without batteries.
With these dimensions and weigths the F-LIDAR IROE 2 can be carried by small aircrafts, like twin engine PARTENAVIA P68 Observer, where the LIDAR system is going to be installed.

Conclusions

With respect to the demands of an "ideal" fluorescence LIDAR outlined in the previous paragraph, the F-LIDAR IROE 2 system fulfils most of the requirements, but it cannot be operated by non-scientific people. Moreover it is a versatile sensor allowing the measurement of a large number of chemical-physical environmental parameters, like natural-water pollution, water temperature and salinity, natural tracer concentration (like yellow substances), phytoplancton concentration, vegetation stresses, etc. The first in field measurements are expected in the second half of 1986.

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