

DEVELOPMENT OF A LIDAR FLUOROSENSOR PAYLOAD FOR SUBMARINE OPERATION

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ABSTRACT

During oceanographic and Antarctic surveys, it is of primary importance to monitor vertical concentration profiles of organic substances and phytoplankton. These substances are stratified in layers floating at different seawater depths, depending on geographical, environmental and biological conditions. In order to determine their distribution, water sampling in the water column is usually performed at fixed sites along selected sea transects.

In the frame of the Italian Research Programme for Antarctica (PNRA), a range resolved lidar fluorosensor has been designed to acquire and store complete Laser Induced Fluorescence (LIF) time resolved signals, from which depth profiles of concentration of different substances and other seawater parameters can be extracted. The first range resolved prototype has been installed at the oceanographic vessel bottom and operated during the XV Italian Antarctic Mission (Jan-Feb. 2000). After testing the prototype, a lidar fluorosensor payload has been designed for subsurface use from a Remotely Operated Vehicle (ROV). The technical layout and characteristics of the ROV payload are presented and discussed, together with preliminary results obtained with the range resolved lidar fluorosensor installed at the vessel bottom.

INTRODUCTION

Scientific and technological research programmes are carried out under the umbrella of the PNRA that is committed for supporting Italian participation to the study of the Antarctic environment and ecosystem. Within the Technological Sector of the Programme, a mobile fluorosensor laboratory has already been developed, equipped with local and remote instruments for continuous operation in the Antarctic areas. The main constituents of the system, a compact lidar fluorosensor capable of single or dual laser excitation of chromophores at the sea surface, a lamp spectrofluorometer, a pulsed amplitude fluorometer (PAM), were lodged into a dedicated ISO 20" container, loaded on the Research Vessel (R/V) *Italica* and successfully operated during the oceanographic campaigns within the XIII (Nov.97 - Jan.98) and the XV (Jan. - Feb. 2000) Italian Antarctic Missions. Thematic maps (1) were produced of different near-surface seawater quality parameters (transparency) and constituents (CDOM, phytoplankton pigments and photosynthetic activity) in the Ross Sea and along the Southern Ocean transect, from Terra Nova Bay up to New Zealand.

Further developments of the programme (1999-2001) foresee the design and realisation of new apparatus for range resolved measurements, aimed to monitor vertical concentration profiles of dissolved organic substances and phytoplankton along water columns several tens of metres deep. Since seawater optical characteristics limit the transmission both of the exciting laser beam and of the generated fluorescence signal at great depths, it is advisable to attempt to follow dynamic modifications along a column by sending the instrumentation on a submersible carrier.

A tethered vehicle, with respect to a fully autonomous one, seems to represent a satisfactory compromise in terms of space and available power supply, mobility, maximum accessible depth and long mission time. A Remotely Operated Vehicle (ROV) carrier has already been developed to conduct underwater studies

in the Antarctic marine environment, mostly at Terra Nova Bay, and inspections under the ice-pack. Results of the planned monitoring missions are relevant to several scientific disciplines, including oceanography, marine biology, glaciology and sedimentology.

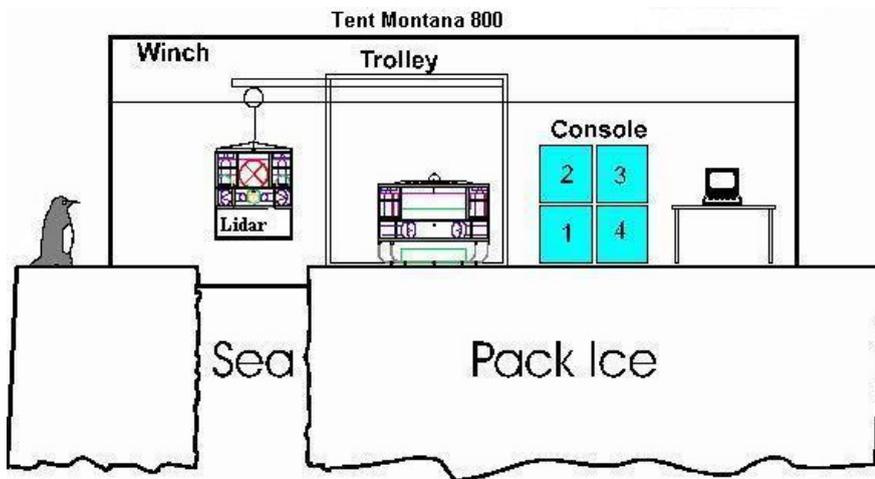
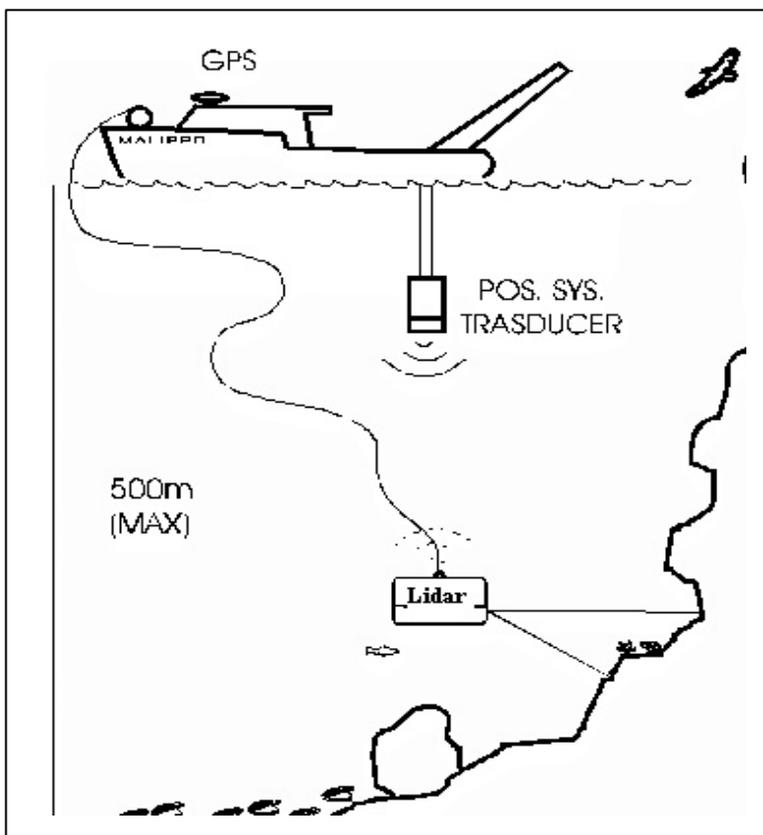


Figure 1: Experimental arrangement during test ice-pack missions, the lidar fluorosensor is lodged at the bottom of ROV.

A new lidar fluorosensor has been designed for installation as an interchangeable package on the Antarctic ROV built and tested at the Robotics Department of IAN-CNR for marine science applications.

The optoelectronic components, including a compact Nd:YAG laser operated in 3rd harmonic and the receiver, have been redesigned in order to fulfil the ROV logistic requirements and to operate in different scenarios, either in Antarctic Seas (the major task for the Programme), or in the Mediterranean Sea. The first Antarctic test is foreseen during the XVII mission (2001-2002), when the payload and its vehicle are planned to participate in scientific activities at the Italian base of Terra-Nova Bay (BTN). Measurements along vertical and horizontal transects will be performed, driving the ROV both from an operational station on the ice and from a small ship. Ground base measurements will be performed at the beginning of the austral summer time, when the ice-pack covers the whole BTN area and the operational station can be positioned on the ice-pack itself, nearby the base.



A tent will be used to assemble and host master and slave instrumentation, the ROV and its payloads will be immersed through a hole on the ice (Figure 1). After the ice-break in the full summer season, the ROV will be operated from a small boat (*Malippo*), hosting the operating station as well. In the latter case, the ROV position will be known with good accuracy after integrating the data supplied by a GPS with a VSBL (Very Short Base Line) acoustic Positioning System (Figure 2).

Figure 2: Scenario of submarine investigation by using the lidar fluorosensor payload from a ROV.

A lidar fluorosensor equipped ROV, operated from a small size ship, offers further possibilities of application in marine ecosystem surveillance, such as ordinary pipeline inspection or sink search in the case of ship accidents, when it is necessary to detect releases of oils or other chemical pollutants. Video cameras and sonar, currently utilised to identify extraneous objects at the sea bottom, are unable to detect seawater pollution, which can be traced by a submersible lidar fluorosensor apparatus.

METHODS

Lidar fluorosensors have already supplied large amounts of real time information on fluorescent targets at sea (2) and on land (3) for diagnostics purposes. These systems were found especially suitable for remote optical observation of phytoplankton and for surface pollution identification. Laser Induced Fluorescence (LIF) spectra collected by a lidar fluorosensor contain signatures of dispersed impurities, such as crude oils, CDOM or phytoplankton, which can be easily extracted (4).

The latest version of the ship-borne mobile fluorosensor laboratory contains a surface lidar fluorosensor. An optical window and an external mirror allow for transmission of both the exciting laser beam and the return LIF signals. The latter, collected by a telescope, after proper spectral filtering, are passed to gated photomultipliers (PMTs) detectors and digitally converted by means of charge-integrating ADC modules. With this approach, only integrated signals are collected, thus losing the fluorescence time decay profile and therefore missing its history and depth distribution. Once the depth distribution is found to be of interest, time integration of signals must be avoided. This implies to increase the system complexity, by adopting a range resolved technique based on fast transient recorders for storing the entire fluorescent echo.

In order to test the performances of a range resolved lidar fluorosensor, a new apparatus has been built and installed at the oceanographic vessel bottom, looking at the water column under the ship. Tests and comparisons between the surface integrated lidar and the range resolved prototype, simultaneously operated from the same boat, have been carried out during the XV Italian Antarctic Mission (Jan. - Feb. 2000). Results have been critically examined and profitably used to define the lidar payload constraints for optimising the successive planned ROV operation.

The present version of our lidar fluorosensor is capable of single or dual laser excitation of impurities at the water surface. In the former excitation scheme, different species characterised by the presence of chromophoric groups (Coloured DOM, algal pigments) can be traced, while operation in the dual excitation scheme, the so-called pump-and-probe technique, allows to directly measure the phytoplankton photosynthetic quantum yield (5,1). The latter operation mode will be implemented as well in the range resolved fluorosensor lidar package for the ROV.

TECHNICAL LAYOUT

Valuable technological improvements in hardware, optics, electronics, and acquisition software are involved in the design and realisation of the ROV instrument, with heavy constraints on ruggedness and reliability. Particular care has been devoted to reduce the weight and size of all lidar subsystems, to minimise the power requirements for laser operation and to maximise its thermal stability with respect to the extreme environmental temperatures (-2°C in the seawater, down to -40°C outside).

The submarine sensor to be developed must be suitable for underwater monitoring up to a 300m depth, both in the Antarctic Ross sea and in the Mediterranean sea. The CNR-IAN ROV can carry scientific payloads with a maximum weight of 150 kg (6,7). The power for operating the instruments is supplied

through an umbilical (500 m long), while an Ethernet connection allows for both remote control and data transmission from/to the operating station (ground or ship based).

The total weight for the lidar package, instrumentation and shelter, should remain within the allowed limit. Furthermore, the external size must be confined within the ROV external structure, in order to reduce possible damages during the submarine shunting. Therefore, particular care has been devoted to reduce mass and size for all the lidar subsystems as well as to keep power requirements for laser operation and electronics to a minimum. The frame for the lidar payload consists of a stainless steel cage, supporting two titanium cylinders, each with a 300 mm diameter and 1100 mm length (Figure 3). The electro-optical components will be installed inside the tubes and two small cylinders, 100 mm diameter, will link them. The thermal instability is a severe problem to be considered, in view of the extreme environmental temperature changes in the Antarctic area, ranging from -2°C , in the seawater, down to -40°C outside and up to 25°C inside the host tent.

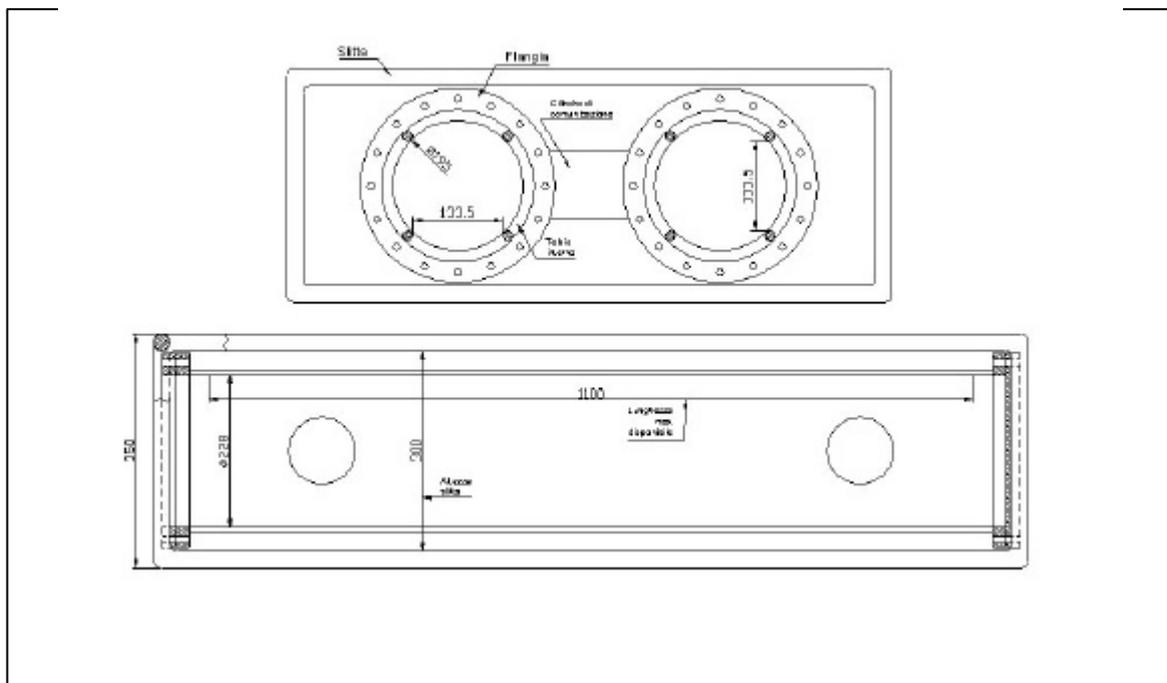
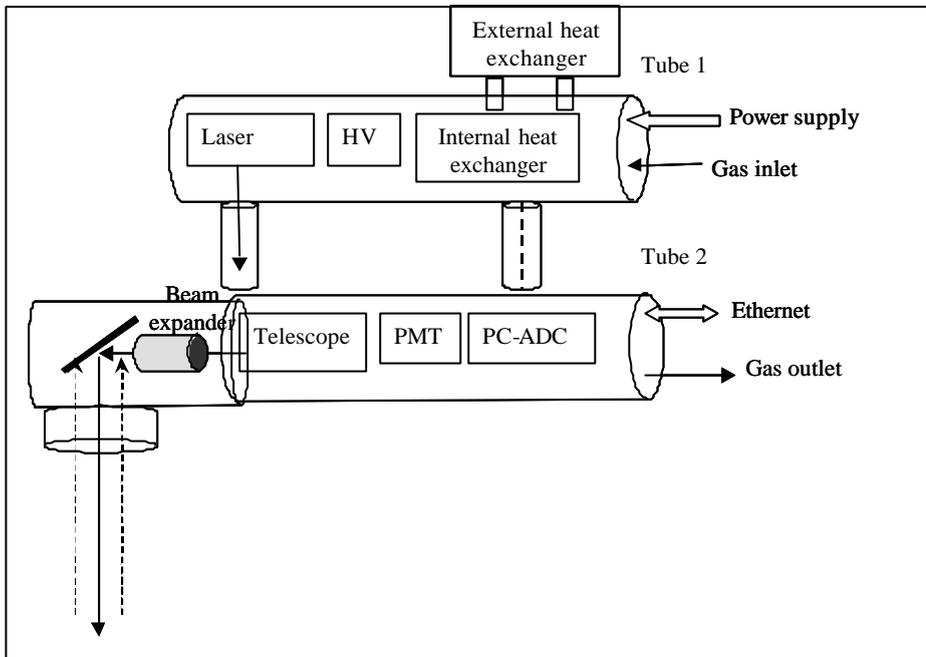


Figure 3: Mechanical frame of the lidar fluorosensor payload for ROV.

The detailed characteristics of the apparatus, including the relative weight, are listed in Table 1. A modular custom designed Nd:YAG laser will be developed to be installed inside the first tube (Figure 4). An internal aluminium cage will host the laser and the high voltage power supply, to let them be easily extractable for external service. The estimated power consumption, at laser running, is in the order of 1 kW, therefore two heat exchangers have been included for temperature control operation. The first one connected to the laser head, hosted downwards the optical plane, should guarantee proper operation in the Antarctic sea, while the second one should be used for the same purpose in tropical areas. In order to prevent freezing and damage to the laser components, the internal water cooling system will be evacuated during hardware transfers through the input/exhaust connection of the first titanium cylinder. The laser source will be equipped with two BBO crystals and the corresponding emissions will be monitored by two photodiodes controlling the motor stabilisation. Internal sensors will be installed for monitoring the water temperature and humidity. An inert gas will be fluxed inside the tubes at high pressure, in order to prevent external arc formations. All the sensors signals, including the high voltage power supply, Q-switch and laser controls will

be transmitted to the computer through an RS232 interface cable. The second tube will host the send/receive optics (beam expander and telescope), the PMT detectors and the computer. The laser beam, through the small connecting tube, will be expanded and directed horizontally or either downwards or upwards by means of an external assembly containing a large mirror. The LIF signals, after being filtered, will be detected by PMTs at the selected wavelengths and stored within four fast transient digitiser PC cards. An industrial PC hosting PCI/ISA slot cards will control all the experimental settings, as well as the acquisition and temporary data storage.



The designed total weight of the payload, including the two titanium cylinders, the internal and external frames and the connectors, is about 90 kg, thus reaching 130 kg once the lidar components are added.

Figure 4: Schematic layout of the lidar payload.

Table 1: Main characteristics of the lidar fluorosensor components to be installed in the ROV payload

Transmitter	Nd:YAG laser	@ 355 nm	Weight /kg
Pump	Energy	30 mJ	
Probe	Energy	3 mJ	
	Pulse length	10 ns	
	Ppr	10 Hz	20
Expander	Variable	3x	
Detectors	Hamamatsu PMT	R-1924 (2), R-1925 (2)	5
Filters	Dichroic	T>90% (@ 400 nm)	
	Interferential	402, 450, 650, 680 nm	
Telescope	Cassegrain	23 cm dia. F#2	5
Fiber Optic	Plastic Multifiber	Four Branches	
	Bundle Diameter	Input 24.5 mm, Output 7 mm	
	Length	50 cm	
Digitizer	Signatec	ISA/PCI 500 Ms/s, 8 bit	
Computer	Axiom AX6050DWP	Passive Backplane	6

PERSPECTIVE

The submarine lidar fluorosensor under development has been designed to remotely monitor range resolved seawater and biological parameters. A typical lidar echo, obtained by the ENEA range resolved system during the XV Antarctic campaign, is shown in

, together with the theoretical curve obtained by fitting experimental data with a theoretical expression for lidar signal (8) and for a total extinction coefficient ($k_T=2.8 \cdot 10^{-2} \text{ m}^{-1}$ at 450 nm). Details on the theoretical approach and experimental apparatus used can be found in the paper “Range resolved lidar fluorosensor for marine investigation”, in this issue. At this wavelength, peculiar to the visible component of CDOM and of heavy crude oils emissions, the maximum depth range is down to 30 m. Due to the seawater optical properties, a much smaller range (about 10 m) can be investigated for the chlorophyll channel at 680 nm. The proposed ROV system, although with a limited operating range on the different channels (10-30m) will be able to investigate accurately a horizontal transect at different depths (down to 300m) and to examine selected sections in vertical columns. For the latter, time series can be planned at the same location in order to study seasonal and daily phytoplankton stratifications.

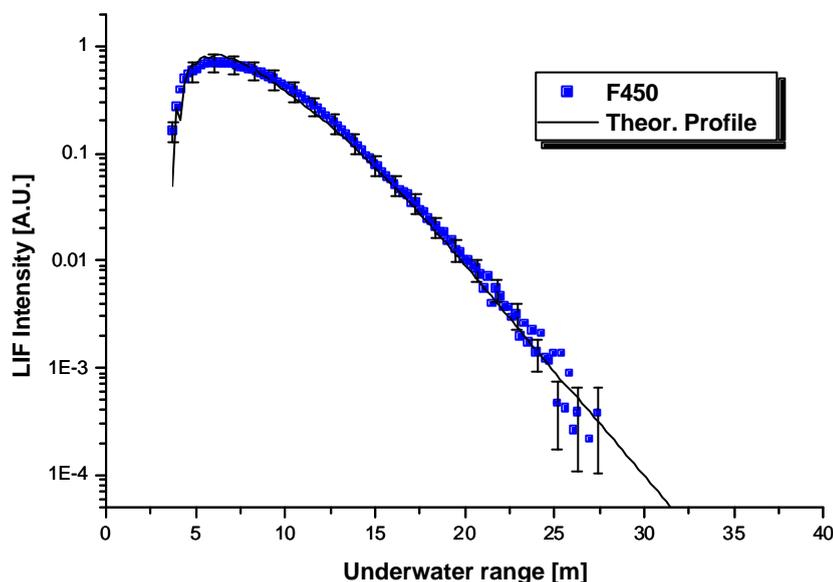


Figure 5: A typical range resolved LIF signal as measured by the ENEA apparatus installed at the ship bottom during the XV Italian Antarctic Expedition in Antarctic Ross sea, Date UTC: 21:30 02/02/2000.

A semi-analytic Monte Carlo radiative transfer model has been developed, introducing the main optical interactions relevant to the LIF technique, and will be used both to optimise the send/receive optical characteristics of the lidar fluorosensor and to evaluate the effects of dissolved or dispersed seawater constituents (9).

CONCLUSIONS

The project of dual mode fluorosensor lidar to be operated from a ROV payload is at quite an advanced stage. Preliminary tests on range resolved measurements have been successful. Data analysis, currently ongoing, will allow to properly size the electro-optical components for the satisfactory collection of data relevant to Antarctic phytoplankton distribution in the Ross Sea.

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