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Scanning lidar fluorosensor for remote diagnostic of surfaces

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ABSTRACT

Scanning hyperspectral systems based on laser induced fluorescence (LIF) have been developed and realized at the ENEA allowing to obtain information of analytical and qualitative interest on different materials by the study of the emission of fluorescence. This technique, for a surface analysis, is fast, remote, not invasive and specific. A new compact setup capable of fast 2D monochromatic images acquisition on up to 90 different spectral channels in the visible/UV range will be presented. It has been recently built with the aim to increase the performances in terms of space resolution, time resolved capabilities and data acquisition speed. Major achievements have been reached by a critical review of the optical design. The results recently obtained with in-situ measurements of interest for applications in the field of cultural heritage will be shown. © 2001 Elsevier Science. All rights reserved

1. Introduction

The application of laser-based techniques as analytical tools in materials science is widespread and very promising by now, also due to the continuous development of the laser technology.

The laser induced fluorescence (LIF) technique is a molecular spectroscopy for surface analysis based on the interaction of the ultraviolet radiation emitted by a laser with matter [1]. It is well known, in fact, that the emission of radiation by luminescent materials is observed whenever an absorption of energy sufficient to activate allowed electronic transitions occurs.

Active remote sensing systems, generally known as lidars (laser radars), have recently found application in high resolution scanning devices for mapping the actual preservation status of cultural heritage surfaces [2,3]. Although it could be easily obtained by the time of flight of the laser pulse, the ranging capability is not exploited in this particular application because the distance of the investigated surface is not useful for conservators who are interested both in structural damages and surface deterioration from either physical or chemical agents, the latter due to surface reaction induced by inorganic and organic pollution. Whatever be the damage, its precise location at the surface is valuable information which can be found in images, especially upon rendering with real or false colors.

Scanning hyperspectral systems based on LIF have been developed and realized at the ENEA in the Diagnostic and Metrology laboratory of Frascati allowing to obtain information of analytical and qualitative interest on different materials by the study of the emission of fluorescence. They have been already used as remote diagnostic tools with successful results on cultural heritage protection and restoration in order to recognize the different used materials or the previous restoration works [4]. Biodegrading agents on stone materials not visible with standard photography have been detected [5,6] and different kinds of marbles have been characterized by means of LIF scanning systems [7]. The possibility to detect and discriminate different acrylic resins on fresco has been also demonstrated both on laboratory samples and on original wall paintings by in situ measurements [8]. However, the capability to give information on materials having specific spectral signature makes these systems usable in several different fields, as in the environmental monitoring [9].

In this work, a new compact setup recently built with the aim to increase the performances in terms of space resolution, time resolved capabilities and data acquisition speed will be presented. 2D monochromatic images on up to 1024 different spectral channels in the visible/UV range can be acquired very fast thanks to the new optical arrangement. With these upgrades, a surface of $1.5 \times 5\ m^2$, for example, can be scanned in less than 2 min.

Several in field campaigns by the here presented LIF scanning system have been recently performed: in the Santa Ana church, in Seville, in order to reveal the effects of former restoration on painted wooden surfaces; in San Augustin church in Marchena, where LIF images were collected from polychromed plaster on the central nave, in order to investigate the occurrence of surface detachment and weak cohesion giving rise to depigmentation; and in the Padua Baptistery dome vault to identify the occurrence of retouches, traces of former restorations and consolidants not otherwise reported in the documentation relevant to the artwork in view of a planned restoration [10,11]. The results from data

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collected during a recent campaign by the ENEA LIF scanning system operated on frescoes in the Virgen del Buen Aire Chapel in Seville will be presented here.

The chapel is inside the monumental complex called “S. Telmo Palace” in Seville, which is now the seat of the presidency of the Andalusian Autonomous Government. Restoration work began in 1991 to convert the entire building for use as the official seat of the presidency. In 2005, a second phase of restoration took place, primarily to restore the structure more to its original configuration, which had been changed considerably by various interventions over the centuries. These restorations concerned also the Virgen del Buen Aire Chapel, an internal chapel which is now open to public visitors. The present study was aimed, in particular, to collect remote fluorescence images of some frescoed walls, in order to reveal traces of former restorations to which the presence of consolidants and retouches on the pigments could be ascribed.

2. Experimental

The main improvement of the new recently built LIF system [12] is on the line by line scanning process, particularly suitable for large areas investigation. A point by point LIF scanning system was, in fact, previously developed in ENEA [13] and applied in several campaigns of measurements due to its reduced size and light weight, that allow for an easy transfer of the system and its operation from scaffoldings, in case of surfaces out of the current maximum range for remote operation (10 m). A picture of the new system is reported in Fig. 1.

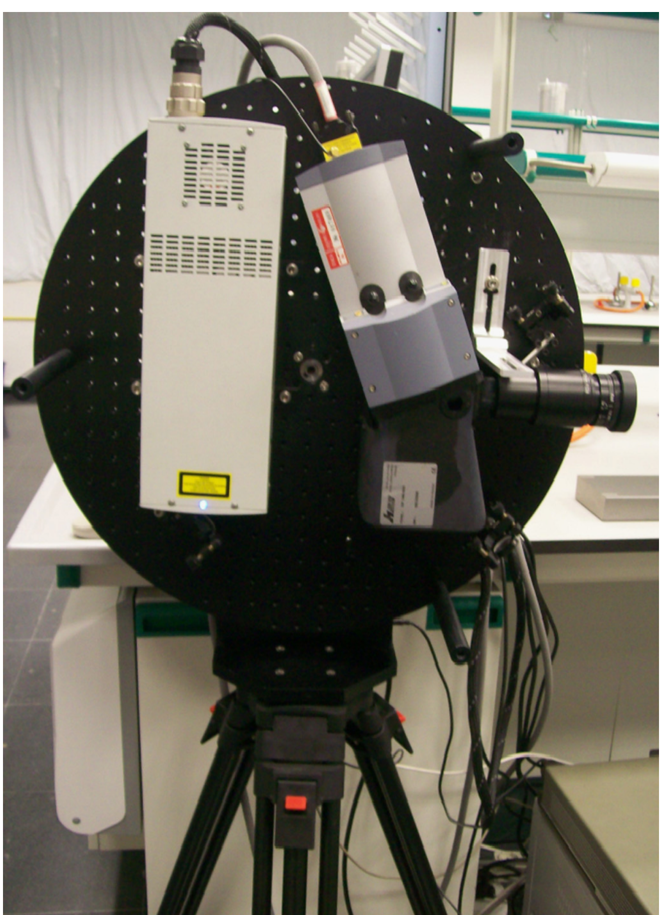

Fig. 1. Picture of ENEA compact LIF line scanning system.

As can be observed, all instruments are assembled on a circular optical table, able to rotate driven by a stepping motor and mounted on a portable tripod. In the new configuration, the focalization mode of the laser radiation has been changed into a line focalization by using a quartz cylindrical lens focusing the laser spot as a line, as shown in the scheme reported in Fig. 2. The laser beam is sent to the target through an elliptical lens and a UV-transmitting 3-element achromatic objective (not shown in figure) is the optical system that couples the illuminated surface to the input slit of the spectrometer. The imaging spectrograph (Jobin-Yvone CP240), 190–800 nm working range, with a square ICCD sensor (ANDOR iStar DH734, 1024×1024 pixel; $13.3 \times 13.3\ mm^2$ active area) replacing the linear array detector, permit obtaining spatial and spectral information in two mutually orthogonal directions, with sub-millimetric spatial resolution and 5 nm of spectral resolution. For this reason the system is named hyperspectral.

It is possible to implement time resolution measurements on the nanosecond scale by controlling the electronic gate of such a detector, collecting time resolved images delayed with respect to the excitation laser pulse.

With the new optical system based on the use of cylindrical lens a surface of $1.5 \times 5\ m^2$ is currently scanned in less than 2 min at 25 m. A diode pumped Nd:YAG laser source has been used to generate the UV radiation at 266 nm or 355 nm, depending on the applications, with repetition rate of 20 Hz, pulse duration 10 ns and energy 1.5 mJ.

During the measurement campaigns described here, the system has worked with the objective able to collect signals either in the UV region from 250 to 450 nm, to detect the presence of consolidants and transparent protective films, or in the visible spectral region from 450 to 700 nm to obtain information on the utilized pigments.

Additionally the LIF scanning system can be used, with the laser switched off, to collect reflectance images upon the availability of an intense standard light source. When using a continuous light source like a lamp, the synchronism for data acquisition is given by the detector itself.

Both fluorescence and reflectance images can be reconstructed in false color by using the three most intense detected bands, corresponding to the main features, as red, green and blue channels (RGB).

Each scan is controlled by a portable computer where a specific program developed in LabView allows to set experimental parameters, to control data acquisition, and to perform a preliminary data analysis. In the main control panel, data are shown both as 2D monochromatic images (1024×1024) and LIF spectra for each pixel.

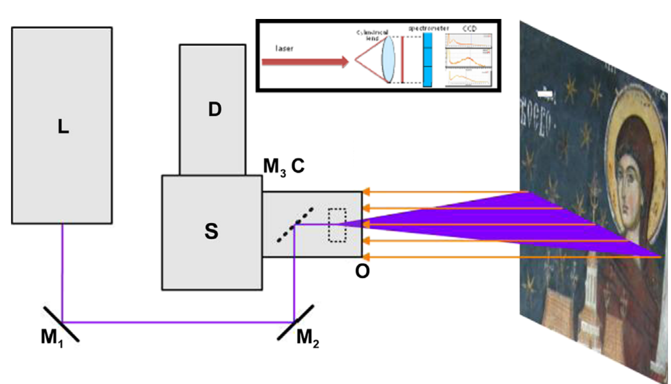

Fig. 2. Scheme of the LIF line scanning system and sketch of the light flow.