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COMPACT SCANNING LIDAR FLUOROSENSOR FOR INVESTIGATIONS OF BIODEGRADATION ON ANCIENT PAINTED SURFACES

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A compact scanning lidar fluorosensor apparatus has been completed and employed in the diagnosis of wall frescos relevant to the preservation and valorization of European cultural heritage. Preliminary laboratory investigations on natural stones and a painted wood icon were performed before the participation to the Advanced On-Site Laboratory for European Antique Heritage Restoration, held in Constanta (Romania), April 15-30, 2004. The scanning LIF (Laser Induced Fluorescence) prototype was utilized during the campaign to investigate painted walls of a Byzantine crypt. Scanned images at different spectral channels and their suitable combination, showing the effectiveness of the technique to reveal the occurrence of biodegradation produced by different microorganisms, are presented.

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1. Introduction

Nowadays, the conservation and preservation of our cultural heritage is one of the world main concerns, particularly in Europe [1,2]. The increasing need for non-destructive investigation tools has become a major issue, as sampling is in most cases restricted in view of the value or the uniqueness of the object. Artworks, as wall paintings in buildings and monuments of historical interest, are affected by environment physical (temperature and humidity) and biological factors (biodeteriogens), and by human (pollutant releases) impact and therefore modified over the time. The knowledge of the behavior of the structure supporting the painting under thermal stress or humidity variations might help to understand how these factors affect the deterioration of an artifact and microbial colonization.

Biodeteriogens are organisms involved in deterioration of artifacts. They are very specific for each type of artifact in accordance with its chemical structure and environment. They also have different nutritional requirements and act directly [3] or indirectly [4] on the substrate. Microorganisms in steps of colonization produce microbiodeterioration. The main intrinsic reasons for the permanent establishment of microorganisms on ancient surfaces are their capacity of adhesion, oligotrophy, metabolic flexibility and tolerance to adverse conditions. The adhesion of microorganisms to a substrate is the result of cell hydrophobicity and of excreted polymeric substances contained by sheaths, capsules and slimes [5].

The presence of microorganisms on an ancient surface can be recognized, after sampling, by morphologic [6] and conventional bio-chemical analyses. However, some microorganisms are

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characterized by the presence of chromophoric groups (e.g. chlorophyll) which allow for their identification by means of non destructive techniques.

The possibility of pigments and biodeteriogens identification in frescos and stone monitoring is offered mostly by vibrational spectroscopy [7], infrared thermography [8], laser induced fluorescence (LIF) [9,10], laser induced breakdown spectroscopy (LIBS) [11], XRF (X-Ray Fluorescence) [12,13], IR and UV emission, with possibility of imaging to different extents occurring in all of them but LIBS. Among them, laser based methods, allowing for in situ or remote characterization of artwork surface, were applied successfully for prospecting [14,15], diagnosis [16 - 19] and maintenance [20,21].

In particular, the LIF technique has been recently applied to the remote sensing of ancient pottery [22], fresco [23] and stone monument surfaces characterized by the presence of pollution and biodeterioration, allowing to detect characteristics invisible with the naked eye while avoiding to move samples from their original location. Large images can be collected once a fluorescence lidar system equipped with a scanning device is utilized [9,10]. The exploitation of new compact laser sources, characterized by a low energy emission occurring in short pulses, guarantees against unwanted ablation effects during the examination of artwork materials, and supports the application of LIF techniques to large surfaces, especially to painted walls for remote monitoring. The fluorescence emission is collected in real time at each examined point during the scanning and, depending on the selected space resolution at the investigated surface, large targets can be scanned in a short time by collecting images on several different spectral channels (e.g. multispectral images excited at the same UV wavelength). In case of LIF investigation of frescos, the analysis of the backscattered radiation can supply additional information on the deepest painted layers and support the false color image reconstruction.

Nowadays the ENEA unit develops laser based instruments for surface remote and in situ analysis on artwork, within the frame of a national project funded by the Ministry of Research and Education. Preliminary tests have been performed at the ENEA laboratory by applying LIF technique to stone materials [24] in order to recognize their nature, reveal their preservation status and detect their presence in an underwater environment, the last topic being of great importance in the Mediterranean area [25]. White marbles and different tuffs have been analyzed, due to their widespread use in classical (Greek and Roman) buildings found in Southern Italy, evidence of the presence of algae on gray tuff, from the characteristic chlorophyll-a spectral signature at 680 nm, was observed.

On the basis of the gained know-how, a compact scanning lidar fluorosensor apparatus has been designed and realized in the laboratory in order to perform the field measurements planned, namely to be employed in monitoring large painted walls or eventually recognize submarine findings. The equipment, after assembling, was tested in laboratory by investigating a painted icon [26]. The present realization is the first attempt to apply LIF technique to fresco and to the problem of biodeteriogens identification. Successively, the ENEA unit has been invited to take part to the CULTURE 2000 action: Advanced On-Site Laboratory for European Antique Heritage Restoration, held in Costanta (Romania), April 15-30, 2004. The invitation included the participation to the planned measurement campaign with LIF scanning and Laser Range Finder (LRF) apparata [27]. The occasion offered a good opportunity for the first field test of the new instrumentation developed.

A Roman funeral chamber and a Byzantine crypt in Tomis (the ancient Constanta), both painted with frescos, were the main sites investigated by using the scanning LIF apparatus. Several multispectral images were obtained and their combination was attempted in order to reveal the occurrence of surface biodegraded area. To this respect, biological samples were collected during the campaign on the examined surfaces of the painted walls and successively reference fluorescence spectra were measured on the grown culture in order to support the assignment of features emerging in LIF images.

2. The scanning lidar fluorosensor

The scanning lidar fluorosensor experimental apparatus was designed by keeping in mind that very often artworks and especially frescos on tombs are placed in small chambers with a narrow entrance, where only a limited space is available. In order to facilitate field operations the optical

and mechanical supports have been assembled on a small size optical bench contained in a box ($50\times50\times100$ cm^3; 10 kg) for easy transportation. The compact LIF system is designed to be coupled with another laser scanning device used for characterization of surfaces: the amplitude modulated LFR, developed in the same laboratory for 3D model reconstruction of object and environments (e.g. whole chambers) [27]. The mechanical mountings are then conceived to offer a rapid and stable hookup to the LRF apparatus in the case of simultaneous operation.

The experimental setup is shown schematically in Fig. 1, and its main components are summarized in Table 1. The compact apparatus (Fig. 2) was first assembled in laboratory and detailed tests were carried on the different optical components [26].

Table 1. Detailed characteristics of subsystems in the scanning lidar fluorosensor.

Laser	Thomson DIVA	Nd:YAG III Harmonic	Diode pumped	λ = 355 nm
			Energy per pulse	6 mJ (max)
			Pulse length	10 ns
			Repetition rate	20 Hz
Spectrometer	Ocean Optics	S2000	CCD linear array	2048 elements silicon
			Detector Range	200 – 1100 nm
			Sensitivity	86 photons/count
		Fiber Optic	SMA 905	Single strand 0.22 NA
			Integration Time	3 ms
Optics		Plane Parallel Mirrors N° 3	ERGAL Aluminum	15 cm diameter
		BK7 Lens	3” diameter.	F = 15 cm
Actuators	NRC	N° 2	Mod. 495-A	Rotary stage
			Travel range	360° continuous
	Resolution	0.001°	Min. Increment. Motion	0.003°

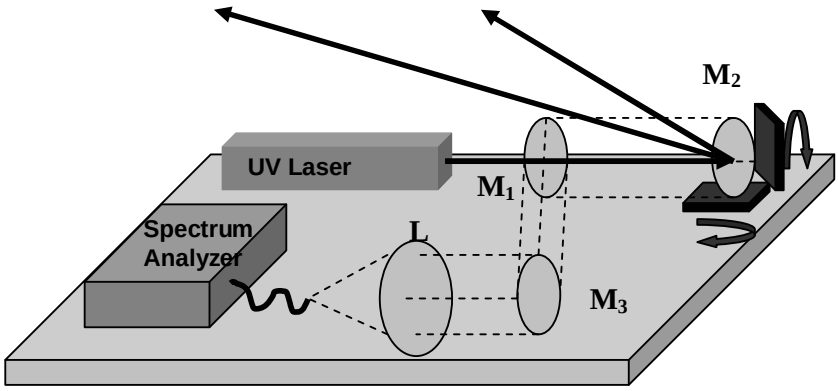

Fig. 1. Lay-out of the compact scanning lidar fluorosensor apparatus. Optical elements are M1 holed mirror; M2 scanning mirror; M3 folding mirror; L collecting lens.

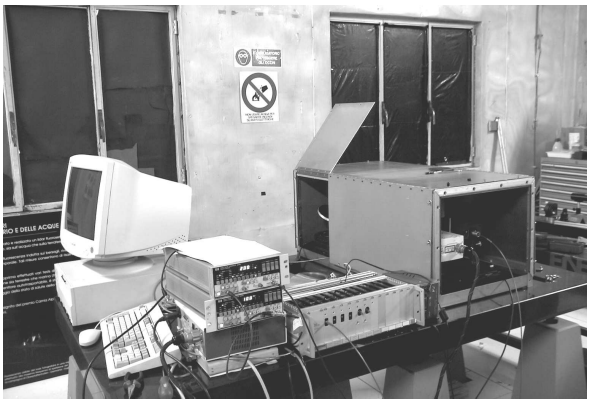

Fig. 2. A picture of the compact scanning lidar fluorosensor apparatus taken during laboratory tests.

The light source is based on a compact pulsed, diode pumped, solid state laser, emitting in the UV (@ 355 nm), while a set of optics (mirrors, lens and quartz fiber optic) allows to transmit the exciting radiation and to receive the scattering and fluorescence signals from the investigated target. Two dichroic UV mirrors separators (HR @ 355 nm) were used to filter out unwanted laser light (fundamental and II harmonic), nevertheless a portion of the 532nm still remains in the output laser beam. This residual radiation has been used as an additional channel to evaluate the target reflectance in the green. The coaxial transmitter/receiver scheme was obtained by using a holed mirror (3 mm diameter in mirror M_1), through which the laser beam passes in order to reach the scanning mirror (M_2), used also for collecting the radiation emitted by the sample. The mirror M_2 is actuated by two rotating servo controls operating at high accuracy.

The fluorescence and backscattered radiation is optically driven by mirrors M_1 and M_3 through the collecting lens (L) and focused at the entrance of a fiber optic, the latter being linked to a compact spectrometer. The CCD detector in the spectrometer permits to record the overall spectral emission with 1 nm resolution in the range from 200 nm up to 900 nm (Fig. 3). Data are transferred to a PC Notebook.

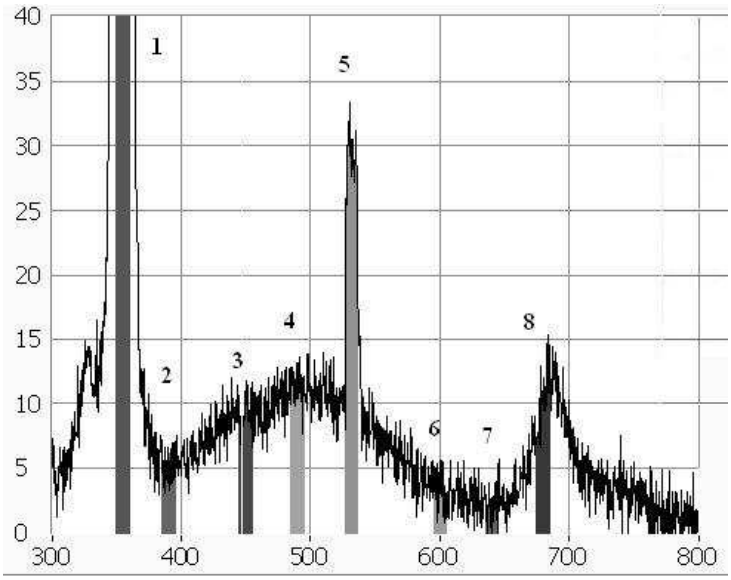

Fig. 3. Laser induced fluorescent spectrum from a biodegraded painted fresco. Eight bands selected for data acquisition are numbered as in Table 2.

The optical transfer function of the apparatus has been optimized at the target working distance, either at 4 m during laboratory tests or at 1.5 m inside the crypt. A phodiode has been placed at the target position, thus simulating the emitting signal and therefore allowing to optimize the efficiency of the apparatus collection optics. A coaxial geometry was adopted to send the laser beam and receive the optical signals; optical aberrations were minimized by employing large mirrors (15 cm respect to 1 cm laser spot size) and by reducing the deflection scanning angle to 8° (full angle), thus ensuring the best optical matching of the system [26].

A dedicated LabVIEW software interface defines the overall instrument settings and data acquisition. The system was conceived to give information about a limited number of spectral bands, but the high resolution spectrometer used and the availability of the full fluorescence spectrum can extend the operational capability of the instrument from multispectral to hyperspectral. The latter operation mode is possible by acquiring as many as 70 contiguous spectral bands with a resolution of 10nm in the spectral range form 200 nm to 900 nm. For the present measurements only a limited number of spectral bands were acquired (typically 8), each of them giving information on the presence and abundance of different chromophores on the surface of the investigated target.

As detailed in the following, the apparatus has been installed inside the underground crypt, in a very critical environment characterized by low space availability, high humidity (RH > 90%) and not negligible dust presence. A testing preselected area was utilized for optimal settings of the apparatus, i.e. working distance, mirrors and fiber optic alignment. Particular care has been paid in avoiding photobleaching of frescos substrate, thus setting the laser peak energy per pulse to a value lower then 0.1 mJ in the spot footprint of about 1 cm^2.

In order to start an image acquisition, a four step procedure was devised: (1) identify the area to be investigated by visual inspection, (2) move motors to drive the laser beam on the upper left corner to set the starting point, (3) move motors to lower right corner to set the ending position, (4) define the spatial resolution in terms of pixels size (usually the same as the laser spot at the target distance). Software controls are given to set spectrometer acquisition details as time integration, number of spectra to average and to select the spectral bands (nominal wavelengths and respective spectral width) to be simultaneously stored (Table 2). Laser backscattered radiations channels (@ 355 nm and residual II harmonics @ 532 nm), together with background channels (@390 nm and 650 nm), were also selected in order to disentangle the main backscattering and fluorescence emission signatures for further analysis. In particular, the backscattered radiation is mainly affected by the absorption of frescos surface layers and results to be a good marker of the line drawings.

Table 2. Spectral bands selected during the acquisition of LIF images of frescos; the spectral width is 10 nm for all of them.

N°	Band [nm]	Assignment
1	355	UV elastic laser backscattering
2	390	UV background
3	450	Blue fluorescence emission
4	490	Substrate fluorescence emission Microorganisms fluorescence emission
5	532	Green elastic laser backscattering
6	600	Yellow fluorescence emission
7	650	Red background
8	680	Chlorophyll fluorescence emission

Tests and field experiments were carried out on dark, in order to achieve a high S/N, while the detector dark current was automatically subtracted from the CCD software itself.

Once the image spatial extent has been defined, and the interesting spectral bands selected, the acquisition chain can start. Actually a repetitive laser trigger signal (20 Hz pulse repetition rate) is generated via software, and it remains on until the pre-selected number of spectra have been acquired and averaged in the spectrometer internal RAM. Then the laser is switched off, spectral

data are transferred via RS-232 interface to the Notebook, and motors are moved to the successive position, where the next pixel acquisition can start. During the image scanning, every acquired spectrum is displayed in real time with the visual indication of the selected spectral bands; a preview of the 2D image under formation on four different spectral channels is also displayed. All data are then saved for further off line analysis.

An overall perception of the scanned area can be gained by building a false color image the investigated area by combining three selected spectral signature in one RGB (Red; Green; Blue) image. The result provides new information on the investigated target, giving details about the occurrence of high intensity color spots, thus suggesting the presence of particular fluorophores group.

The procedure used to obtain an RGB false color images is here briefly summarized. The first step deals with background subtraction: to this end the wavelength position and width of a suitable spectral region to be used as background is identified by a close examination of a typical fluorescence emission spectrum, and the corresponding band integrated signal is subtracted from each spectral channel. Then it is possible to select three bands (R = @ 680 nm, G = @ 532 nm and B = @ 450 nm, listed in Table 3), and to associate them with the RGB colors. Actually this procedure was designed to deliver graphical output on a standard VGA device, with a theoretical resolution of $3 \cdot 2^8$ colors. The final image is thus obtained applying the following algorithm, combining three grey scale images in just one colored image: each pixel P_i of the combined image has a value given by

$$P_i = R\left\lfloor 255\frac{p_{i,C_R} - p_{C_R,\min}}{p_{C_R,\max} - p_{C_R,\min}}\right\rfloor \oplus G\left\lfloor 255\frac{p_{i,C_G} - p_{C_G,\min}}{p_{C_G,\max} - p_{C_G,\min}}\right\rfloor \oplus B\left\lfloor 255\frac{p_{i,C_B} - p_{C_B,\min}}{p_{C_B,\max} - p_{C_B,\min}}\right\rfloor \quad (1)$$

where

R, G, B is the color code

$\oplus$ indicates color combination

$\lfloor\ \rfloor$ is the integer part operator

p_{i,C_j} is the spectral intensity of the i-th pixel of channel C_j (with j = R, G ,B)

$p_{C_1,\ \min}$ $p_{C_1,\ \max}$ are 5% and 95% threshold of the intensity histograms of the fluorescence emission, for the channel C_j (with j = R, G ,B)

Table 3. Spectral bands employed in the RGB false color image release.

Emission	Name	Elaboration	Notes
Red	F680	Channel #8 – Channel #6	Red emission
Blue	F450	Channel #4 – Channel #6	Blue emission
Green	F532	Channel #5 – Channel #4	Green elastic laser channel

3. Biological sampling protocol

Since many organic compounds show a blue broad band emission, all of them have a humic-like spectral features with only minor or slight differences, only a direct in-situ sampling can be used to confirm or reject hypothesis on the real nature of the blue fluorescence contribution. In data analysis, different areas with high blue content, strongly emerged (S/N > 50). On the basis of LIF

experimental observations, we were able to precisely localize in real time the points deserving biological sampling for successive biological culture and laboratory fluorescence analysis.

Samples for microbiological analysis were taken during the campaign under sterile conditions by using collection swabs EUROTUBO from the area with specific morphology for biodeterioration. Samples were immersed in 10 ml of sterile saline solution, stirred for 15 min and then diluted. From each dilution 1 ml of the suspension was inoculated in MEA (malt extract agar) media. After 21 days of growth at 28°C it was counted the number of developed colonies and studied their morphology. For identification purposes, different laboratory approaches were adopted such as analytical cultural characteristics and morphology (color of aerial and submerse mycelium, shape, growth and margins of colonies smell etc), microscopic characteristics (hyphae color, presence of septum, arising of conidia, size, shape color of conidia etc.) and physiology (growth, fermentative abilities, biosynthesis of enzymes and pigments).

A complete list of fungal strains isolated in the crypt is reported: *Alternaria alternata, Aspergilus niger, Aspergillus versicolor, Aspergillus fumigatus, Aureobasidium pullulans, Chaetomium globosum, Cladosporium cladosporioides, Epicoccum purpurascens, Fusarium oxysporum, Penicillium citrinum, Ulocladium sp, Schizophyllum commune.*

4. LIF scanning field measurements in Constanta

The "Advanced on-site laboratory for European antique heritage restoration" project carried on within the European action CULTURE 2000, coordinated by the National Museum of History and Archaeology in Constanta (Romania), represented an innovative way of collecting multidisciplinary synergies and European contributions aimed to the preservation of Ancient Cultural Heritage. Measuring activities were carried on in different archaeological sites, including the painted funeral chamber and the crypt in Tomis (the ancient town of Constanta).

The Byzantine crypt found under the courtyard of the Liceum "Mihai Eminescu" in Constanta was examined in detail by the scanning LIF instrument. A planimetry of the chamber is shown in Fig. 4 together with the indication of one of the scanned area reported in the zoomed picture as an example. Largely damaged frescos, painted with the *a secco* technique, were still present showing zoomorphic and phytomorphic images together with geometric decorations. Colors remaining at the painted surfaces were mostly red, green and black. Some green biodegraded spots could be recognized also with the naked eyes, where algae started to grow. The partially preserved painted area included the side walls and part of the vault in the main chamber, nearby the entrance stairs.

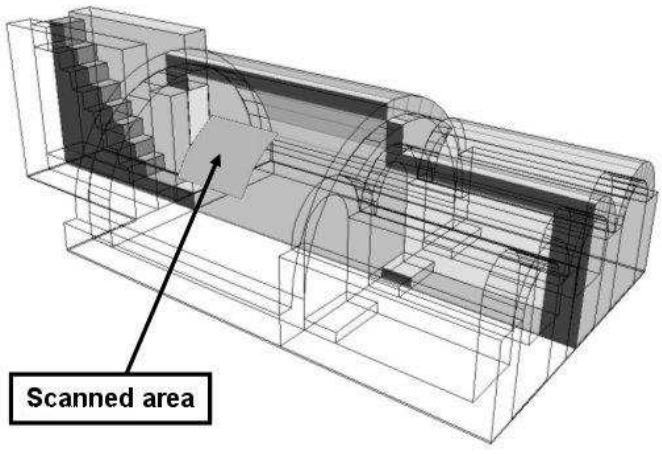

Fig. 4. Planimetry of the Byzantine crypt examined in Constanta (internal dimension: 5 m length, 3 m width, 2 m maximum height). The arrow points to the scanned area with the painted birds, shown in detail in Fig. 8.

The scanning LIF apparatus was installed inside this chamber and seven frames were collected at different spatial or pixel resolution. The main acquisition parameters are summarized in Table 4, note that the last frame belongs to a Roman tomb also examined in Tomis, where fragments of a fresco with human figures are presented. A total of eight frames were considered from April 22th to 25th, with different investigated widths and pixel resolution, respectively. The last parameter strongly affected the total duration of the acquisition.

As discussed in details in the next section, on the examined frescos the occurrence of extraneous pigments coming from microbial attack emerged from the multispectral analysis. Meanwhile, the capability to localize them and reconstruct the overall drawings due to the high resolution of the scanning apparatus was demonstrated.

5. Results and discussion

Multispectral LIF investigation were carried on entire wall frescos thus revealing different peculiarities due to the presence of various pigments and to the plaster employed to realize the painting. In antiquity, *a secco* frescos were obtained by applying adhesive binder flakes on plaster, thus obtaining not stable layers on the surface. Present work is mainly focused on the preservation status of the painted walls, while a complete characterization of the plaster is needed in order to identify chemical constituents and the crystal structure of pigments.

Plaster is formed by a two-layer or in a few cases by a three-layer structure (fine clay on surface, calcite in middle and coarse clay as base), subsequently covered by pigments and binders and therefore not observable. In case of poor conservation status (with uncovered spots), superficial layer are removed and plaster emission appears as intense broad band fluorescence peaked in the blue spectral region (data not shown) characterized by a wavelength profile and time constants which usually largely differ both from pigments and biodegradation agents.

The pigments found on the painted wall have strong absorption in UV-blue region, also efficiently quenching the fluorescence signal from underneath layers. The observed difference in emission intensity easily allows to discriminate the pigmented drawing with respect to plaster, giving rise to an intensity scaled images in which clearly appear the detail of flower and geometric shape of the drawings. As the elastic laser backscattering @ both 355 and 532 nm is concerned, we notice that emission from pigments, complementary colored with respect to the excitation wavelength, gives rise to signal with the highest contrast when compared with unpainted surface. In this case also we obtain images containing the outline of the painted drawings. Microorganisms (bacteria, fungi and algae) have occasionally been detected in some selected spots, mainly occurring in the partially scraped areas of plasters or along the border of wall were the preservation status is worst; their identification has been made by assigning emissions in the blue and red spectral regions.

Presence of biodeteriogens, manly algae grown on monuments, was already laboratory characterized [28] and remotely monitored over historical buildings [10] by adopting LIF technique. In the present experiment, a part from algae attack, the occurrence of large spots relevant to fungi community was revealed and characterized for the first time.

Table 4. Details of the investigated frames during the Constanta CULTURE 2000 campaign.

Frame	Date	Time	Pixels		Frame width [mdeg]		Note
			X	Y	Delta_X	Delta_Y	
1	22/04/2004	1h	60	60	9000	7000	Red/green flowers
2	22/04/2004	2h 45m	100	100	7000	7000	Red/black drawings
3	22/04/2004	1h 30m	70	70	5000	5000	Red/green flowers
4	23/04/2004	5h 30m	140	140	10000	5000	Red/orange flowers and birds
5	24/04/2004	1h	60	60	1500	1500	Bird neck – detail
6	24/04/2004	2h 45m	100	100	5000	5000	Detail of Frame #4
7	24/04/2004	9h 30m	180	180	9000	9000	Detail of flowers and birds
8	25/04/2004	55m	40	80	4000	8000	Standing figure (tomb)

As an example of the identification capability of the LIF instrument, we report in Fig. 5A a digital camera picture of a decoration detail (Frame #2 of Table 4), approximately the same area is then compared with the lidar grayscale image (Fig. 5B) obtained by the green elastic channel (@ 532 nm). As it can be observed, dark red and green-grey decorations are quite well evident. Images from the blue and red fluorescent channel taken respectively @ 680 and 490 nm are shown in Fig. 6A and Fig. 6B in grayscale. In these images it is possible to identify specific locations with very high signal intensity, in which the contribution of microorganisms possibly dominates. Three spots were encircled in the digital picture of Fig. 5A, in order to be compared with the corresponding zones in Fig. 6. The fluorescence image @ 680 nm (Fig. 6A) highlights two intense areas assigned to the presence of algae (circles #1 and #2), while a larger area with different microorganisms attacking the painted wall was revealed in the blue spectral channel @ 490 nm (Fig. 6B; circle #3).

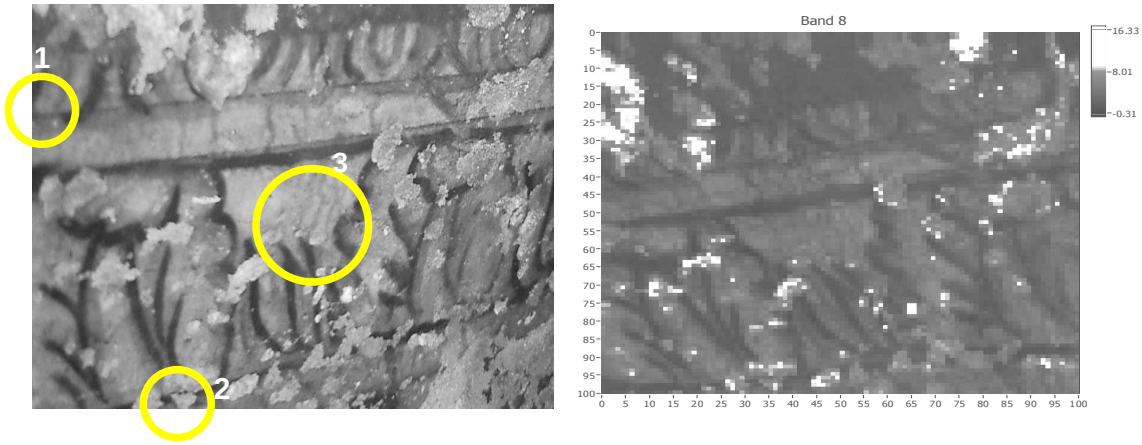

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Fig. 5. Frame #2 of Table 4: A) color picture of the investigated area; B) grayscale image obtained @ 532 nm. Yellow circles mark areas where microorganism presence was found.

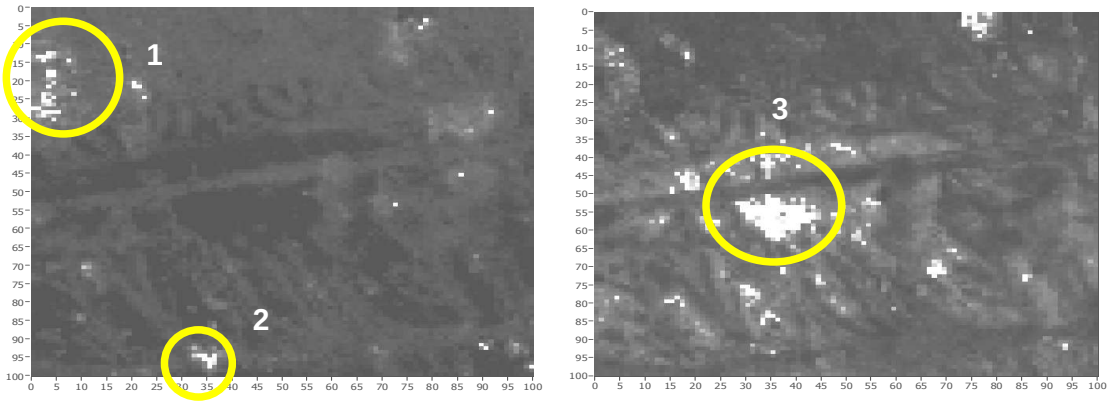

Fig. 6. Grayscale spectral images of Frame #2 of Table 4: A) 680 nm channel; B) 490 nm channel.

Monuments built in stone are mainly colonized in the first steps by phototrophic (cyanobacteria, algae and lichens) and chemotrophic microorganisms [29,30]. Similar organisms were found in the archaeological sites of Constanta on the way of daylight coming in, the typical chlorophyll emission from green algae can be recognized in the spectrum of Fig. 3 near 680 nm. Although the amount of light is extremely low, as noticed in previous work [29], we found a very good growth of photosynthetic microorganisms. This may be due to their adaptation to a low photon fluxes and their capabilities to adjust photosynthesis and pigments to the spectral composition and intensity of available light. Limitation of light can also stimulate the production of exopolymeric compounds from sheath of Cyanobacteria, where absorption of cations and precipitation of calcium ions in the form of calcium carbonate takes place.

Fungi by their hyphae penetrate into decayed limestone, calcitic and dolomitic stones or produce pitting through their chemical action. Fungi have been associated with staining chelating and powdering of stone surface [30]. Evidence of microorganisms spectral signatures were carried on successively by means same LIF scanning apparatus in laboratory experiments, as collected inside the Byzantine crypt in Constanta. Among them, *Ulocladium sp.Schizophyllum commune* is one of the most frequently fungi on mural painting. It is a dry mushroom with fruitbodies on branches and trunks of deciduous trees, stumps and logs. Cap with 1-4 cm diam. has furrowed margin, greyish white with pointed scales leathery. Gills radiating from the point of attachment are rolling back and became grey brown. Spores are white and cylindrical. In particular, on the wall of the Byzantine crypt were sampled hypha and spores not fruitbodies. Mural painting is not specific substrate for *Schizophyllum commune* but wood. This evidence suggests that unfortunately the crypt in the past was a place to deposit wood. The large broadband emission observed in the blue spectral region (Fig. 7) confirms the assignment to *Ulocladium sp.Schizophyllum commune* to large blue fluorescing areas found in the crypt's fresco.

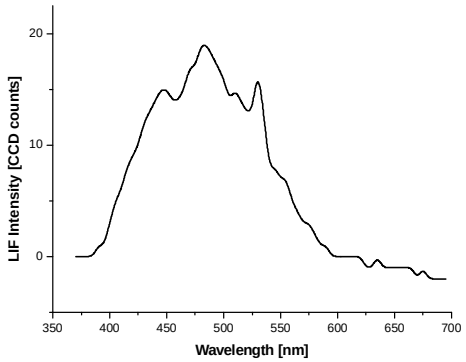

Fig. 7. LIF spectra of *Ulocladium sp.Schizophyllum commune* obtained upon excitation at 355 nm.

Fig. 8. RGB image of Frame #2 of Table 4.

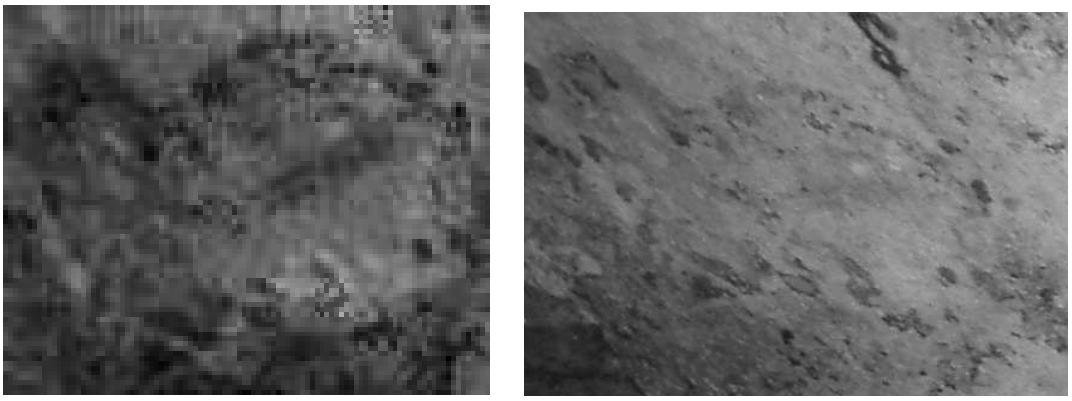

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Fig. 9. Frame #6 of Table 4: A) color picture of the investigated area; B) RGB image, with evidence of fungi (blue spot) and algae (red spots) over the fresco surface.

Successive data elaboration proceeded in the integration of the three spectral laser scanned images (R = @ 685 nm, G = @ 532 nm and B = @ 450 nm), by adopting the algorithm of eq. 1, in order to retrieve a false color RGB image where all the features related to biodegradation can be contemporary recognized over imposed on the original drawing. The composite RGB image obtained form bands of image #2 is shown in Fig. 8. In this reduction, the presence of algae is evident on the upper left corner and on the bottom, as small red spots, while a large blue area

indicate the occurrence of microorganisms in the middle part. Algae show tendency to growth in places where light radiation is available, even at low intensities. More evident is the case frame #6 (Fig. 9A), where in the RGB image of Fig. 9B red and blue spots emerge inside and outside the wall fresco. Furthermore, Fig. 9B shows that the ability of the instrument to reproduce the light red and dark green decorations of the painted drawings is remarkable.

6. Conclusions

The new compact laser scanning LIF apparatus has successfully operated during the Constanta campaign in monitoring different fresco's surfaces whose stage of preservation is relevant for cultural heritage. The apparatus has demonstrated the capabilities to implement the multispectral technique in order to monitor fluorescence bands, related to pigments and microorganism presence and therefore to retrieve information on deep layer of the paintings by the use of the backscattering radiation (@ 355 and 532 nm).

The adopted technique allowed to collect different information with respect to conventional visible or infrared digital cameras, especially concerning the attack of microorganisms. The occurrence of fungi has been remotely sensed and confirmed by laboratory analysis.

The successive merging of images relevant to three main spectral colors in a unique false color reconstruction seems to be a very promising technique to visualize differently biodeteriorated areas. The possibility of superimposing this kind of fluorescence images with the 3D model obtainable my means of the laser range finder apparatus [27], also demonstrated during the same campaign, offers a further facility for the precise location of damaged areas.

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