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REPORT ON LIF MEASUREMENTS IN SEVILLE. PART 1: VIRGEN DEL BUEN AIRE CHAPEL

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Abstract
Within the frame of a scientific cooperation between ENEA UTAPRAD (Frascati) and UPO Natural Sciences Dep. (Seville), aimed at developing and testing innovative diagnostic instrumentation for Cultural Heritage preservation, this report deals with results obtained in a joint campaign carried on in Seville during February 2010. Namely the data acquired by the ENEA LIF scanning system operated on fresco's in Virgen del Buen Aire Chapel are presented here. The Virgen del Buen Aire Chapel has been studied according to the Research Project of "Non Destructive Techniques" managed by IAPH (Consejería de Cultura de la Junta de Andalucía). The results have been also implemented as part of a conservation project carried out by IAPH. LIF images are discussed in term of evaluating former restoration actions, in particular retouches on pigments and consolidant additions on a painted wall and two vaults. Statistical approaches and projection operators have been utilized for elaborating the images in order to handle the large number of spectra collected in each scanned point by our hyper-spectral system.

Key words: *Laser Induced Fluorescence, consolidant identification, chemical residuals on painted wood*

RAPPORTO SULLE MISURE LIF IN SEVILLE. PART 1: CAPPELLA DELLA VERGINE DEI BUEN AIRE

Riassunto
Nell'ambito di una collaborazione scientifica fra ENEA UTAPRAD e il Dip. di Scienze Naturali dell'Università di Siviglia "Pablo de Olavide", volta allo sviluppo e alla sperimentazione di strumentazione innovativa per la conservazione di Beni Culturali, si riportano qui i risultati ottenuti in una campagna congiunta eseguita a Siviglia nel febbraio del 2010; Nello specifico presentiamo i dati acquisiti mediante il sistema LIF scanning dell'ENEA utilizzato per eseguire misure sugli affreschi nella cappella della Virgen del Buen Aire, condotto nell'ambito di un progetto di ricerca su tecnologie non distruttive diretto dallo IAPH. Questi risultati fanno parte del progetto di conservazione condotto dallo IAPH. Le immagini LIF raccolte sono discusse per evincervi la capacità di estrarne informazioni su precedenti azioni di restauro, in particolare riguardanti ritocchi dei pigmenti e aggiunta di consolidanti. A seguito della gran mole di dati raccolti su ciascun punto tramite il sistema di rivelazione iperspettrale, nel corso del lavoro per elaborare le immagini sono stati utilizzati approcci statistici operatori di proiezione, come descritto nel testo.

Parole Chiave: fluorescenza indotta da laser LIF, identificazione di consolidanti, sostanze chimiche su legni dipinti

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REPORT ON LIF MEASUREMENTS IN SEVILLE PART 1: VIRGEN DEL BUEN AIRE CHAPEL

1. Introduction

Along a scientific cooperation already started in 2008 between ENEA UTAPRAD (Frascati) and UPO Natural Sciences Dep. (Seville), aimed at developing and testing innovative diagnostic instrumentation for Cultural Heritage preservation, the first joint campaign with ENEA non destructive laser diagnostic tools has been carried on in February 2010. Specific aim of the campaign was to test remotely the performances of our new LIF (Laser Induced Fluorescence) – scanning system on real painted CH surfaces. As test sites in Seville some fresco's in the Virgen del Buen Aire Chapel (S. Telmo Palace) were selected, while in Santa Ana church wooden decoration were examined. This report deals with data collected on the first target, where traces of former restoration (retouches and consolidants) were searched for.

The Virgen del Buen Aire Chapel is located inside the monumental complex called "S. Telmo Palace" in Seville, which is now the seat of the presidency of the Andalusian Autonomous Government. Construction of the building began in 1682 outside the walls of the city, on property belonging to the Tribunal of the Holy Office, the institution responsible for the Spanish Inquisition.

Restoration work began in 1991 to convert the entire building for use as the official seat of the presidency of the Andalusian Autonomous Government. 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 closed to public visitors.

2. Experimental apparatus

Our LIF scanning system is capable to collect hyperspectral fluorescence images scanning large areas for applications to Cultural Heritage surfaces (e.g. fresco's, decorated facades etc …). A new compact set up has been built (patented in 2010) aimed 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 and consequently of the detector utilized:

- the focalization mode has been changed into a line focalization by using a quartz cylindrical lens and a imaging spectrograph (Jobin-Yvone CP240);
- the linear array detector, responsible for the multichannel spectral resolution, has been replaced with a square ICCD sensor (ANDOR iStar DH734, pixel size 13 μm), mounted behind a slit parallel to the laser line footprint during the scanning.

This arrangement is characterized by having the spatial and spectral information on two mutually orthogonal directions imaged on the detector, with submillimetric spatial resolution and a spectral resolution better than 2nm. Additionally it is possible to implement time resolved measurements on the nanosecond scale by controlling the electronic detector gate.

The overall current system performances are horizontal resolution 640 pixel, 0.1 mrad angular resolution, minimum acquisition time per line 200 ms, FOV aperture 5.7° (corresponding to a scanned line of 2.5 m at 25m distance). With the latter optics an image of 1.5 × 5 m is scanned in less than 2 minute at 25 m.

The compact arrangement is shown in Figure 1a, in the inset details of the optical layout are given.

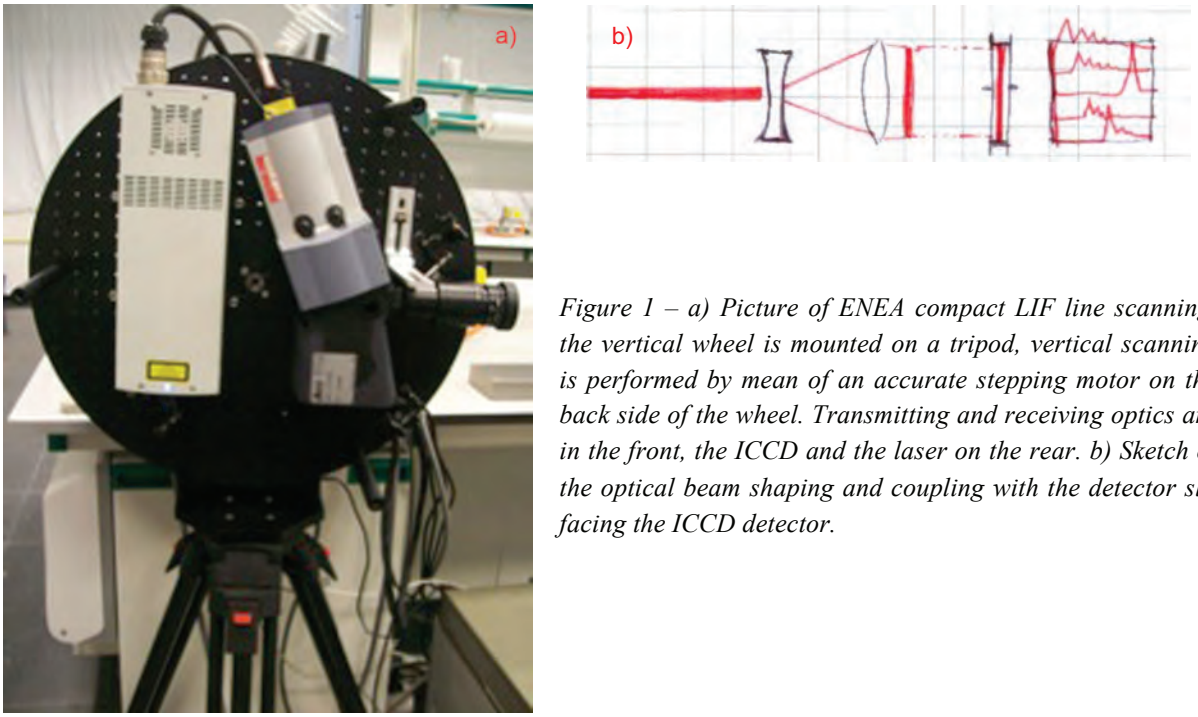


Figure 1 – a) Picture of ENEA compact LIF line scanning, the vertical wheel is mounted on a tripod, vertical scanning is performed by mean of an accurate stepping motor on the back side of the wheel. Transmitting and receiving optics are in the front, the ICCD and the laser on the rear. b) Sketch of the optical beam shaping and coupling with the detector slit facing the ICCD detector.

Performances of the realized instrument are based on the spectral signature characteristic for each chemical compound laying on the examined surface. The detection of the emitted fluorescence radiation allows to identify different material utilized, which is needed in view of a planned restoration. In fact it reveals with high space resolution the occurrence of retouches, traces of former restorations and consolidants not

otherwise reported in the documentation relevant to the artwork, and to identify extraneous materials onto the surface (degraded substances, pollutant, waxes, some kinds of biological attack such as microalgae and fungi).

2.1 Operating modes

Because of the different focal plane position for UV and VIS, caused by the use of refractive collecting optics, it is necessary to acquire at least two scans, each one optimized for a different optical collection, in this way we assume to obtain comparable detecting efficiency and spatial resolution in al the spectral range for the very broadband radiation collected after laser excitation at 266 nm.

Actually three successive scans were made: in the first the collecting optics was focussing the UV region from 250 to 450 nm, in a successive scan the VIS spectral region from 450 to 700 nm; in the last scan the laser is switched off, a halogen/tungsten lamp is turned on and the optical detector shutter remains opened for a time needed to acquire a reflectance image in the visible spectral range.

2.2 Data Analysis

The most relevant spectral features of LIF spectra are identified by Principal Component (PC) analysis. Although the PCs do not possess any direct physical meaning, they can conveniently be described in terms of bands; since the LIF spectra result from linear combination of PC with appropriate weights (scores), the presence of bands in PC may have a close correspondence on actual emission bands.

As shown in the analysis here reported, a given PC usually has well defined peaks and bands, while sometime exhibits complex shapes and frequent is the case of bands with opposite sign swing. The occurrence of bands in PC is here considered as an indication of the existence of a physical bands which will be searched for in the actual LIF spectra. Few of the PC components are usually considered for band analysis: typically 5 to 8 components are enough to describe the entire spectral data set.

In the present report the PC analysis is devoted to the identification of prominent spectral features, thus relieving from the time consuming examination of each acquired spectra. Advantages of this procedure can be found because it is fast and can run in a semiautomatic mode, however it has the inconvenience to give a global analysis, possibly ignoring those local peculiarities which do not possess enough statistical significance to be represented in the considered PC. To overcome this drawback a detailed local analysis is performed on subsets of the scanned areas, and the PC are analyzed separately. Once identified, spectral bands are sought for in the acquired LIF spectra, completing the data analysis.

A different method used in the analysis of spectral images, concerns the identification of pixels having a specific spectral content. Typical is the case of identification of a given pigment: such task is accomplished either by a band analysis, or by using spectral mapper algorithms like SAM (Spectral Angle Mapper) or SCM (Spectral Correlation Mapper). Although the mapper algorithms perform well with a low computational cost, their performances are generally lower with respect to the entire band analysis procedures.

3. Scanned fresco's surfaces

In the Virgen del Buen Aire Chapel LIF scans were made on frescos located in four different positions, namely along the decorated wall (scans A31 to A33), the vault on the central aisle (scan A34 to A37 along

East-West direction and A38 to A40 along the North-South), the vault on the main entrance door (scan A34 to 39). Details of the experimental conditions for each scan are reported in Tables 1 to 4.

Table 1 – Image acquisition settings for scans A31 to A33

Scans	**A31**	**A32**	**A33**
Gate	500 ms	500 ms	500 ms
Gain	200	200	230
Laser current	100 A	100 A	100 A
Halogen lamp	500 W	OFF	OFF
Optical f#	22	3	3
Spectral focus	VIS	VIS	UV
Back-ground	Y	Y	N
Lines	300	300	300
Scan width			
Distance	3.2 m	3.2 m	3.2 m
Notes	Reflectance image	LIF image	LIF image

Portion of the fresco painted wall with delimitation of the scanned area. Real dimensions are approximately 35 cm x 90 cm, Image size is 128 x 300 pixels.

Table 2 – Image acquisition settings for scans A34 to A37

Scans	**A34**	**A35**	**A36**	**A37**
Gate	500 ms	500 ms	500 ms	500 ms
Gain	200	200	230	230
Laser current	OFF	OFF	100A	100A
Halogen lamp	2000 W	2000 W	OFF	OFF
Optical f#	22	22	3	3
Spectral focus	VIS	VIS	UV	UV
Back-ground	Y	N	Y	N
Lines	300	1000	300	300
Scan width	25000	25000	25000	25000
Distance	11.2 m	11.2 m	11.2 m	11.2 m
Notes	Reflectance image	High resolution reflectance image	LIF image	LIF image

Portion of the fresco painted wall with delimitation of the scanned area (4.5 m^2). Real dimensions are approximately 120 cm x 360 cm, Image size in pixel is height 128 and width with a variable number of pixels (see left side).

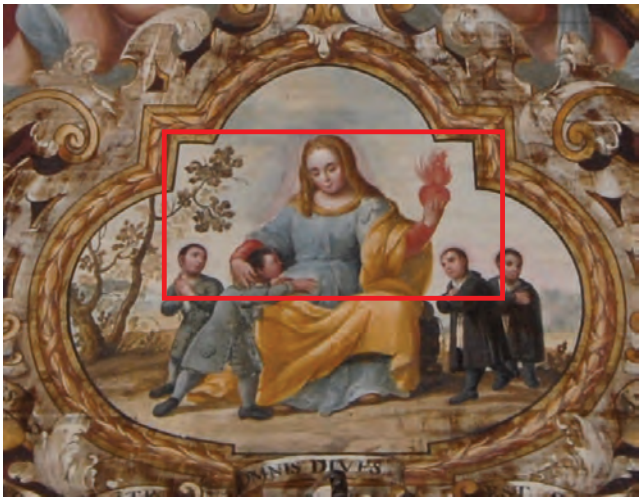
Table 3 – Image acquisition settings for scans A38 to A40

Scans	**A38**	**A39**	**A40**
Gate	500 ms	500 ms	500 ms
Gain	230	230	230
Laser current	100 A	100A	OFF
Halogen lamp	OFF	OFF	2000 W
Optical f#	3	3	22
Spectral focus	UV	VIS	VIS
Back-ground	N	Y	N
Lines	600	600	600
Scan width	11000	11000	11000
Distance	11.2 m	11.2 m	11.2 m
Notes	LIF image	LIF image	Medium resolution reflectance image

Portion of the fresco painted wall with delimitation of the scanned area (2.5 m^2). Real dimensions are approximately 120 cm x 200 cm, Image size in pixel is height 128 and width with a variable number of pixels (see left side).

Table 4 – Image acquisition settings for scans A41 to A44

Scans	A41	A42	A43	A44
Gate	500 ms	500 ms	500 ms	500 ms
Gain	220	80	220	230
Laser current	OFF	OFF	100 A	100 A
Halogen lamp	2000 W	2000 W	OFF	OFF
Optical f#	22	3	3	3
Spectral focus	VIS	VIS	VIS	UV
Back-ground	N	Y	N	N
Lines	300	150	150	150
Scan width				
Distance	3.8 m	3.8 m	3.8 m	3.8 m
Notes	Reflectance image	Low resolution reflectance image	LIF image	LIF image



Portion of the fresco painted wall with delimitation of the scanned area (0.3 m^2). Real dimensions are approximately 38 cm x 80 cm. The image size in pixel is height 128 and width with a variable number of pixels (see left side).

3.1 Analysis of images on fresco wall (A31 – A33)

A portion of a decorated wall was used to demonstrate the capabilities of LIF analysis on frescos. The LIF stystyemc was placed at 3.2 m distance from the target and the image was scanned with a spatial resolution

of approximately 0.003 m. The scan size is 128 pixels width, 300 pixels height and 250 spectral channels from 250 nm to 800 nm (Figure 2).

Figure 2 – a) Conventional photo of the scanned fresco surface, b) RGB reconstruction from scan A31 (reflectance image) with spectral channel at 60 9nm, 508 nm, 405 nm.

Fluorescent bands identification

Some peculiarity of the image can be extracted by the careful examination of single pixel spectra. To this purpose two approaches have been used: the first makes use of spectra averaged on selected areas characterized to have an apparent uniform colour, while with the second approach the PCA (Principal Component Analysis) the principal components are computed. On one hand with the first technique it is possible to document the use of pigments. On the other hand the use of PCA, although giving spectral components not having any direct physical meaning, could identify prominent emission bands eventually hidden in the observation of image reconstruction, as that shown in Figure 2, or occurring in areas not sampled or not analyzed with the first technique.

As expected the spectral content of scans acquired in different condition is strongly different. Figure 3 showscc the PC of scan A32 and A33 acquired respectively with the focus in the VIS and in UV spectral region. The elastic backscatter at 266 nm is visible in both of the plot of Figure 3, however since this wavelength is strongly attenuated its amplitude is not driving in saturation the detector. The UV components show a strong emission with peaks at 282 nm, 304 nm, 325 nm, 362 nm. The first three peaks however seem correlated (see Figure 4a), and their presence could possibly be related to an incomplete or not perfect radiometric calibration of the detector.

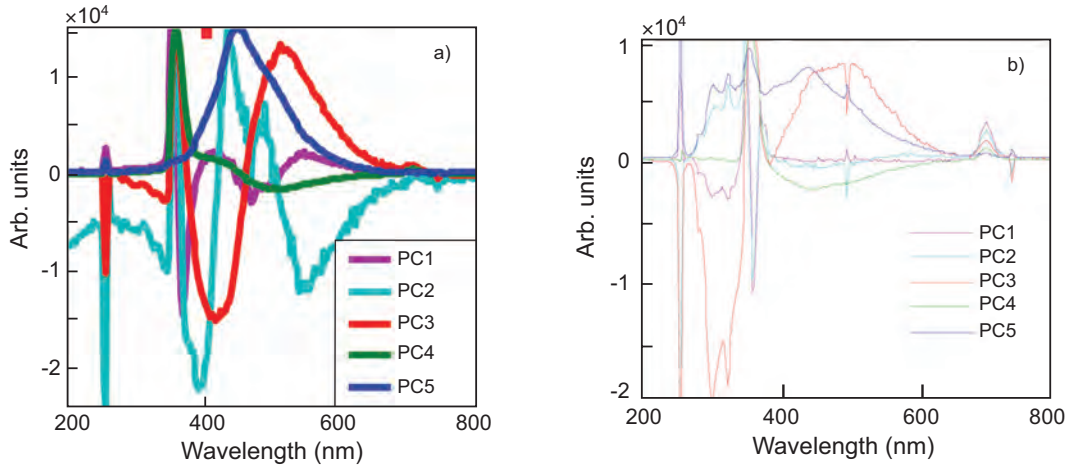


Figure 3 – PCA analysis of images A32 a), and A33 b).

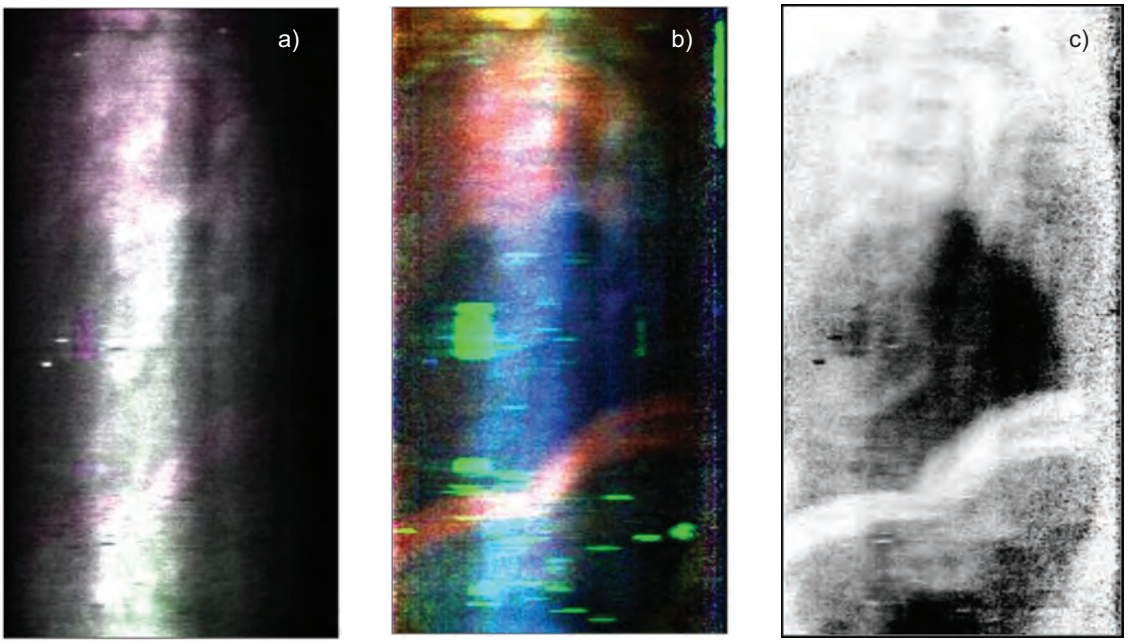


Figure 4 – a) RGB false colour reconstruction from image A33 with bands at 325 nm, 304 nm and 282 nm. The predominance of grey colours indicate a rather strong correlation among the used channels. A partial exception is found in the band 325 nm since the upper part of the image is slightly dominated by red colour. b) RGB false colour reconstruction from image A33 with bands at 450 nm, 360 nm and 325 nm. The predominance of green colour indicates the presence of a strongly emitting compound at 360 nm. c) band ratio analysis: the F330 is normalized to F450 band. Grey levels are used to indicate the band ratio values (dark grey levels corresponds to high bands' ratio values).

cIn the red region of the spectrum in Figure 3b we observe a relatively small bump around 720 nm. It is an artefact of the spectrometer corresponding to the second diffraction order of the strong emission at 360 nm. Similarly the spectral structure at 532 nm is the second diffraction order of the 266 nm, while the peak at 798 nm corresponds to the third diffraction order.

Figure 5 shows the band analysis of the F310 peak normalized to the F450 band.

A close correlation could be observed by comparing the images of Figure 4c) and Figure 5c). Although these images comes from different bands' ratio, and show different features of the same portion of the analyzed fresco, both use the F450 as normalization channel: actually it results for the appearing of a faint character and consequently explaicn the observed correlation.

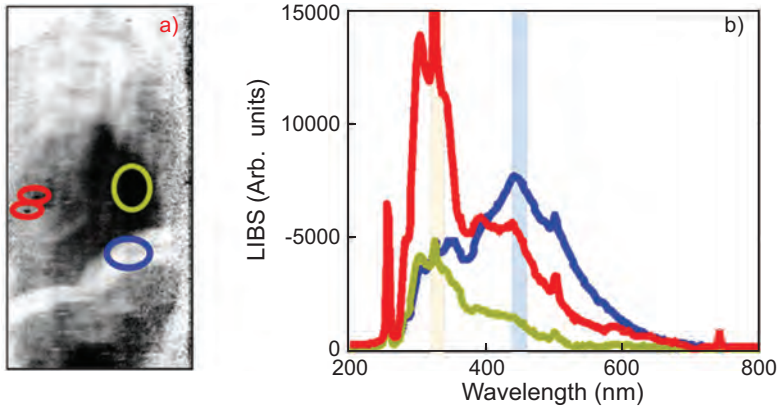


Figure 5 – Band ratio analysis in UV region. F310 is normalized to F450 band. a) The analysis on A33 scan gives grey levels are to indicate qualitatively the band ratio values (dark grey levels corresponds to high bands' ratio values). b) shows the LIF spectra on selected areas by colour line correspondence.

Although partially correlated cthe presented results are extremely useful for a prompt coarse analysis.

Identification of retouches or consolidated areas

Figure 6 shows LIF spectra taken at some selected areas of the scanned area. At the present moment it is not possible to identify the chemical compounds related to the observed strong emission around F360 nm, however it could presumably be of different origins, for example:

- retouched or freshly repigmented areas
- consolidant film
- protecting layer

In case of assignment to consolidant, best candidate seems to be within the paraloid family that in our former data base [2], built on plaster, shows a peak nearby (paraloyd B72 at 332 nm). A precise identification or discrimination is not immediately possible with the limited data base available, it is worth notice that we have an extremely good localization of the use of such chemical; moreover the gray level scale gives a qualitative evaluation of the amount of film used. A quantitative relation is not yet established; however a direct proportionality between the film thickness and the intensity of LIF signal should hold. The band ratio F360/F450 is shown again in Figure 7, zhere LIF spectra fro, selected regions are evidenced and reported in the right side. A close examination of Figure 7, shows that such chemical is almost everywhere used; the fresco portion in the upper left side is sligthly treated (see for example the fresco portion near the face of the represented Saint), while on the right side we observe more intense LIF signals.

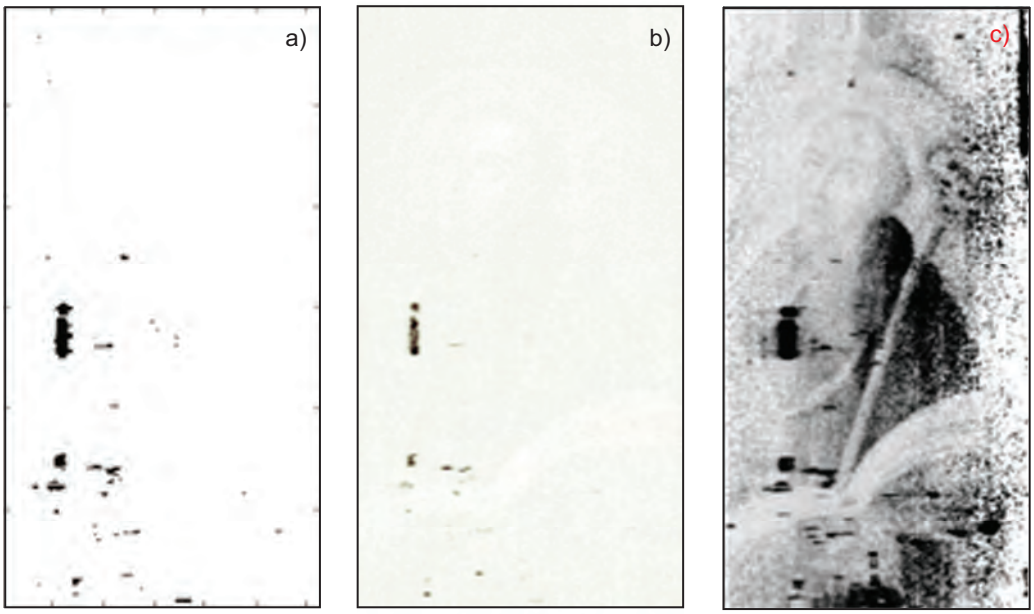


Figure 6 – a) SAM similarity map for identification of areas with a prominent fluorescent emission at 360 nm, b) band analysis: absolute band intensity F360, c) band ratio analysis: the F360 is normalized to F450 band, (dark grey levels corresponds to high bands' ratio values).

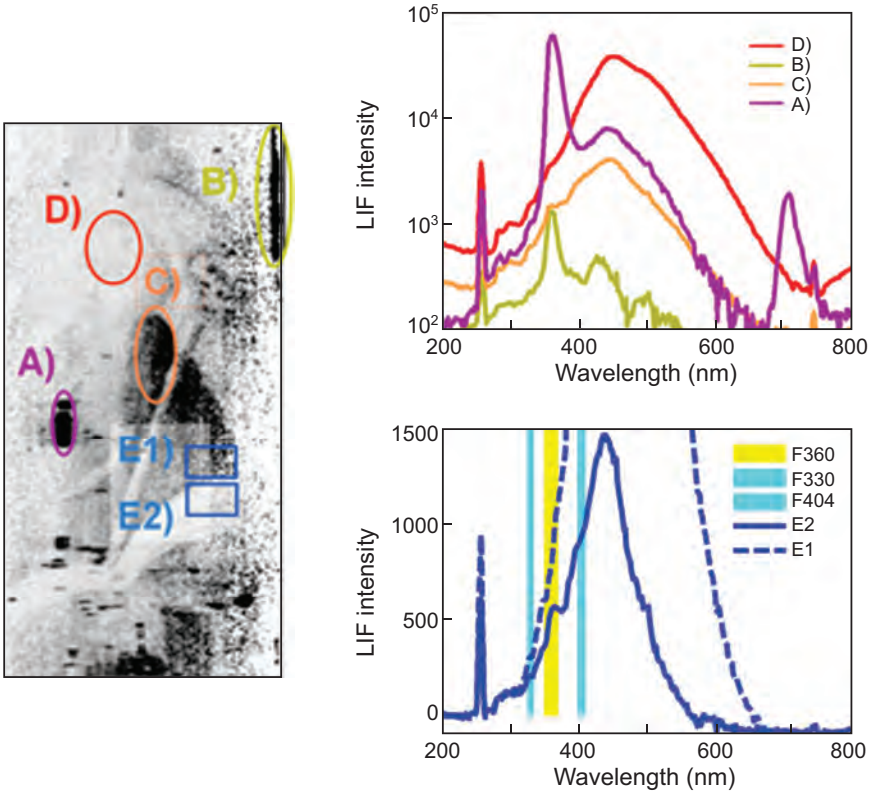


Figure 7 – LIF spectra from selected areas of scan A32, log scale in upper plot in areas identified by letters A) to D), linear scale in lower plot in areas E1) and E2).

The algorithm used to get the image in left part of Figure 7 produces an artifact on those areas in which the fluorescence at 450 is deeply modulated, since fresco's regions with high intensity fluorescence band at F450 (e.g. in the region near the face or in the lower part of the book area E2) tend to have low ratio's vales. Indeed this is responsible for the appearing of a low contrast image barely visible in the background. To check the artifact due to normalization, two special points were tested in the areas E1 and E2 and the fluorescence spectra are reported respectively in the bottom plot of right side. Here a significant difference on the band at F360 is clearly visible: this feature can be interpreted by assuming a different interaction between superficial film on one side and pigment and plaster on the other, suggesting that the white pigmented facilitate the penetration of the chemical on the surface, consequently causing its thickness reduction.

Further study is now in progress to understand the nature and the origin of the film, nonetheless the LIF images till now acquired document its spatial distribution.

3.2 Analysis of images on main vault (A34 – A37) – first part

Two different portions of vault were analyzed for the purpose of retouch identification, documentation of binders, consolidants, and for pigment analysis. The scanning system was placed on the floor just under the vault at a distance from the target of approximately 11.2 m. The first selected area was analyzed with 4 acquisitions (scan # A34 to A37) in the UV, visible range and reflectance image. The spatial resolution of approximately 0.006 m, while the scan size are 128 pixels height and typically 300 pixels width (corresponding to the number of scan lines), to test the system capabilities also a high resolution scan with 1000 lines was also acquired (A35 scan).

The conventional photograph shown in upper part of Figure 8 is for comparison purpose only, actually it

Figure 8 - a) Conventional photo of the vault with fresco, b) RGB reconstruction from 300 lines scan A34 (reflectance image) with spectral channel at 609 nm, 508 nm, 405 nm.

appears dark, with a poor resolution, while the image acquired with the scanning system (see Figure 8a) has a complete colors saturation, with a number of better defined details, like for example the angels' faces all around the dove of peace. It is worth notice that this fact in itself does not demonstrate an absolute better imaging capability of the scanning system with respect to the conventional one.

Fluorescent bands identification

From the observation of the spectral components as computed by PCA algorithm, we can identify several feature deserving consideration, namely the following bands do constitute prominent emissions in the analyzed fluorescence spectra (from Figure 9b and 9c): F280 nm, F325 nm, F340 nm, F360 nm, F420 nm.

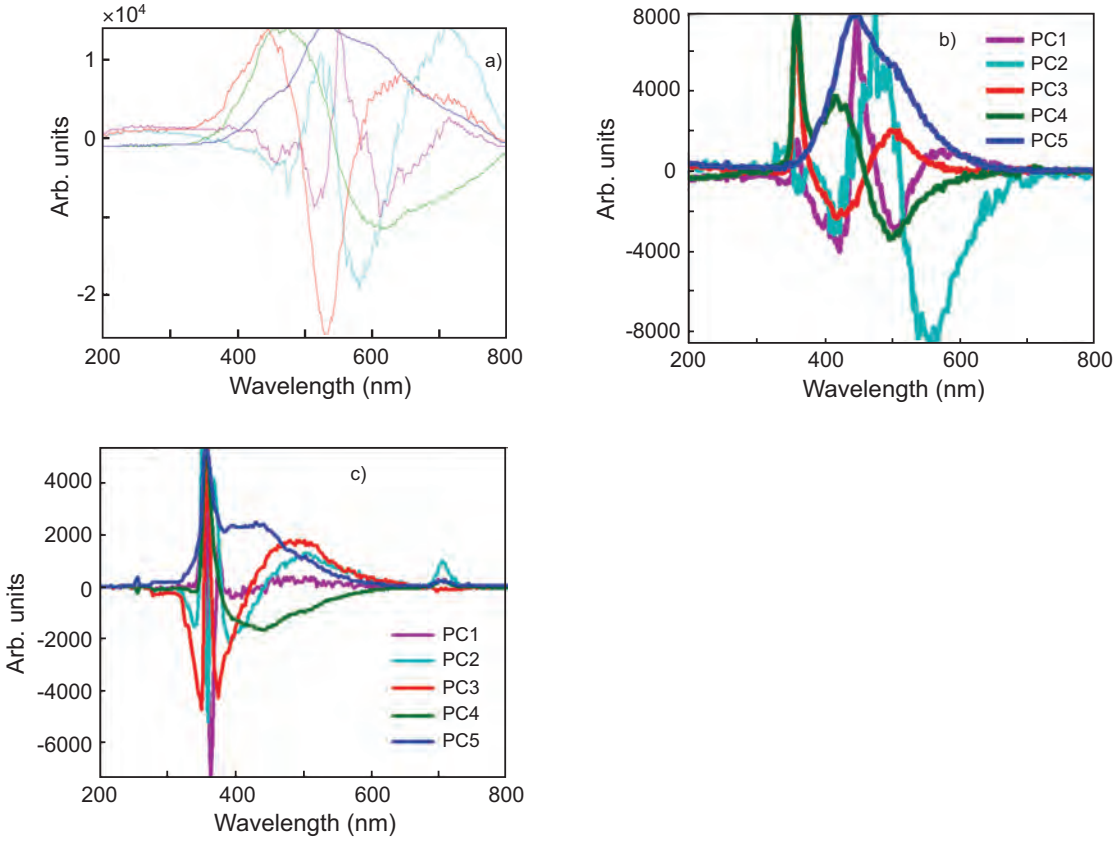


Figure 9 – PCA spectral components of images A34 a), A36 right side b), and A37 lower left c)

Identification of retouches or consolidated areas

The identification of areas which have been heavily treated during the restoration can be documented by using the band fluorescing at 360 nm. As previously pointed out, we are not sure of the chemical compound responsible for such strong fluorescent band. To ascertain its origin further laboratory study and reference material characterization still need to be completed.

The fluorescence image with the band at 360 nm is shown in Figure 10 and 11. Two different way of presenting data are there reported: firstly the absolute band emission at 360 nm is shown in a black and white image. The black corresponds to pixels with high fluorescence emission intensity, while white area with low florescence. A similar image is shown in Figure 11, where the F360 nm emission is corrected for the

background (linearly interpolated by using the side bands at F341nm and F372 nm) and then normalized to the F450 nm. The comparison between the images of Figures 10 and 11 shows richness of details on upper image. Since it might be interesting to differentiate between the large black area on right side with the lighter appearing on right side, the average LIF spectra in three selected areas identified by symbol A), B) and C) is reported in the plot of Figure 12. It demonstrats a tendency to underestimate the presence of emission band when using the too simple correction algorithm here used. To

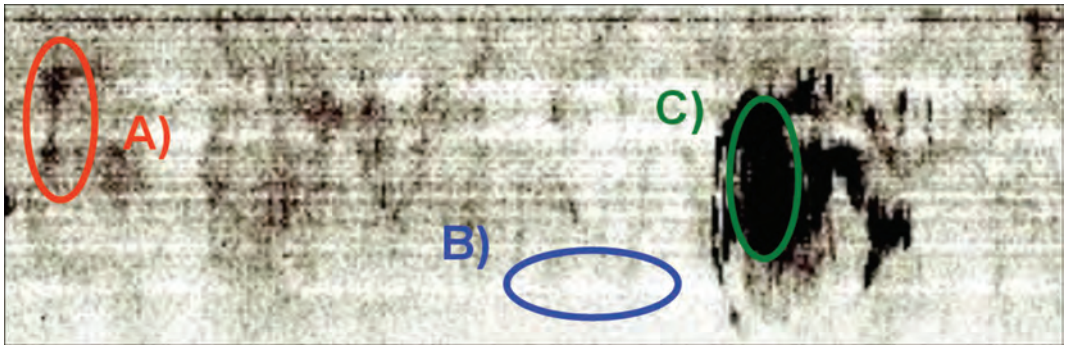


Figure 10 – Absolute F360 band (scan# A36) intensity image (upper pane). Grey levels are used to quantitatively indicate the band values (dark grey corresponds to high band intensity).

Figure 11 – Background corrected F360 band (scan# A36) normalized to F450 intensity image (middle pane). Grey levels are used to quantitatively indicate the bands' ratio (dark grey levels corresponds to high bands' ratio values).

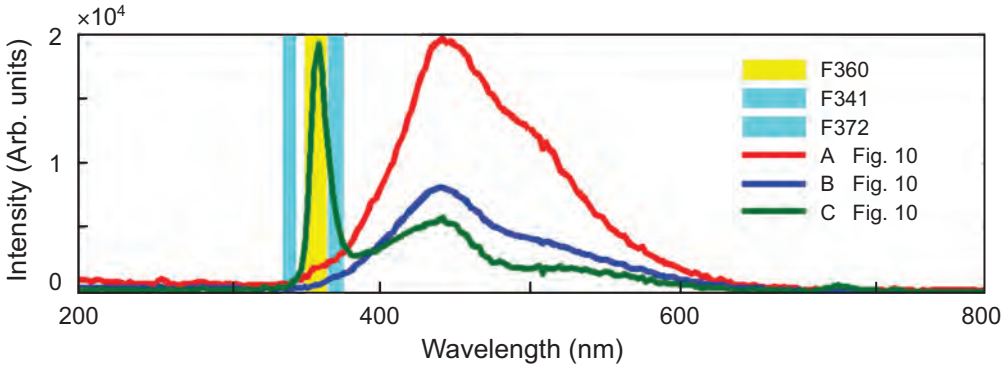


Figure 12 – LIF average spectra in areas identified by letters A), B) and C) in the Figure 10; the position of signal and background bands is also shown.

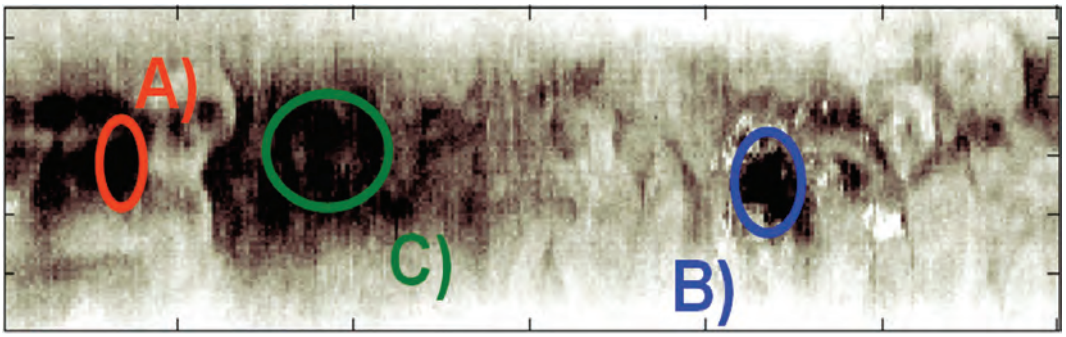


Figure 13 – Absolute F282 nm fluorescence (scan# A37)

Figure 14 – Background corrected, not normalized F282 nm band, (scan# A37)

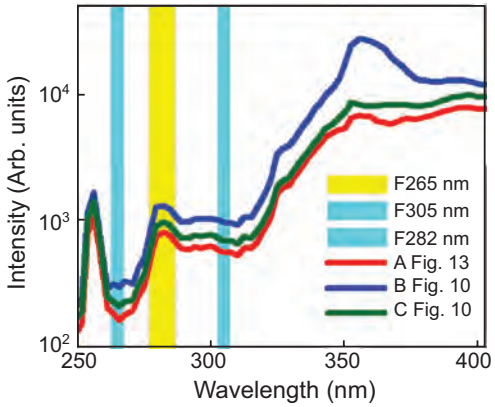


Figure 15 – B/W image with the F280 nm emission band. Areas with high fluorescence intensity are darker.

the purpose of quantitative indication a calibration measurements is mandatory, while a signal compression (e.g. by using a log scale) could enhance the weak band emission, thus facilitating the identification of treated areas.

Figure 13 and 14 show a band analysis of the F282 emission; indeed as demonstrated in Figure 15 the only representative spectral feature is peaked at 280_290 nm. Figures 16 and 17 show false colour representation of the same scan with different spectral content; blue color dominates heavily treated arcos in Figure 16, while the blue colored regions in Figure 17 correspond to the F280 spectral feature.

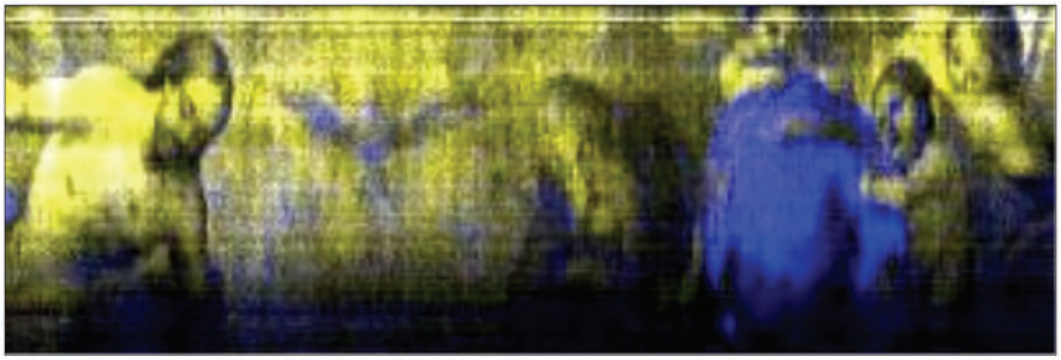


Figure 16 – Two colours image is used to better document the restoration process treated. Areas to have prominent F360 nm emission band in blue; grey areas are uncertain; yellow areas are minimally treated.

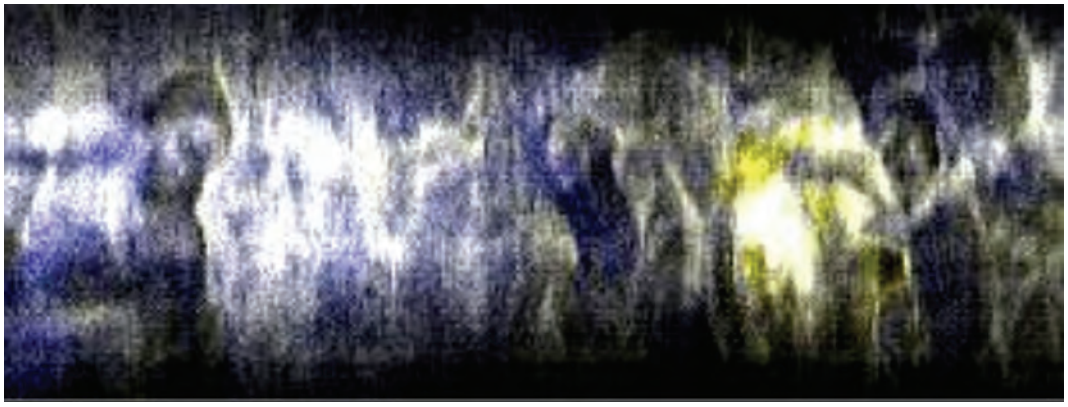


Figure 17 – Two colours image is used to compare the emission bands at F282 nm (predominance of blue colour) and F340 nm (dominated by yellow colour). Note that yellow regions are very close to areas dominated by the F360 nm band, and - for that reason - could be affected by spectral interference (scan# A37).

3.3 Analysis of images on main vault (A38 – A40) – second part

A second portion of vault was analyzed for the purpose of retouch localization, identification of binders, consolidants, and for pigment analysis (Figure 18). The selected area was analyzed with 3 acquisitions (scan # A38 to A40) in the UV, visible range and as reflectance image. The spatial resolution was approximately 0.006 m, while the scan size are 128 pixels height and 600 pixels width.

Fluorescent bands identification

Band identification is performed by PCA as described in the previous section; the spectral loading are shown in Figure 19a,19b,19c. Its worth notice a prominent spectral feature at 360 nm, which dominates almost all spectral loading.

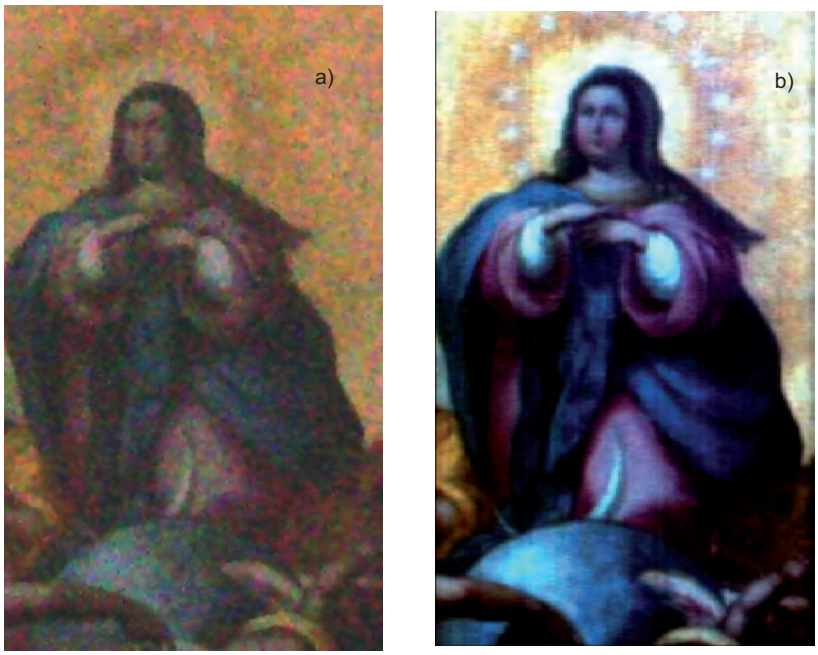


Figure 18– a) Conventional photo of the scanned fresco surface, b) RGB reconstruction from reflectance image A40 with spectral channel at 609 nm, 508 nm, 405 nm.

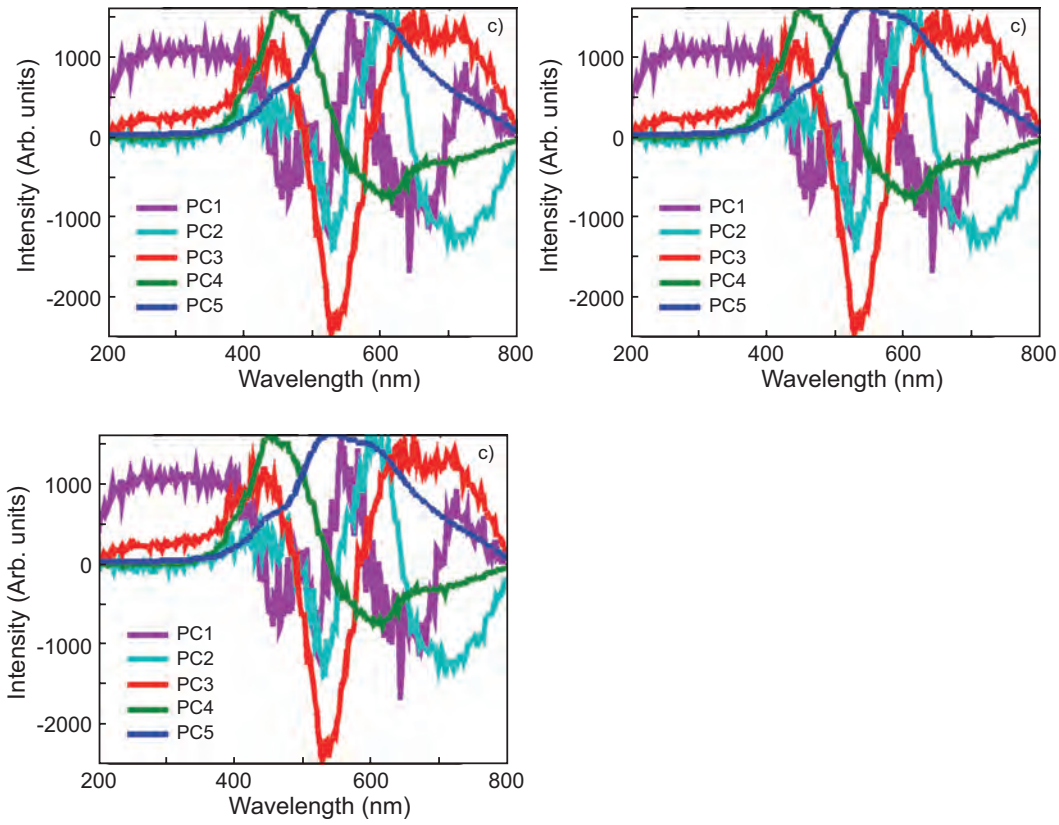


Figure 19 – PCA spectral components of images A38 a), A39 right side b), and A40 lower left c).

Identification of retouched or consolidated areas

The identification of retouched or consolidated areas is performed as previously described. Figures 20a, 20b, 20c and 20d show the result of different data processing algorithm; although different in the details all of them localize the same treated areas.

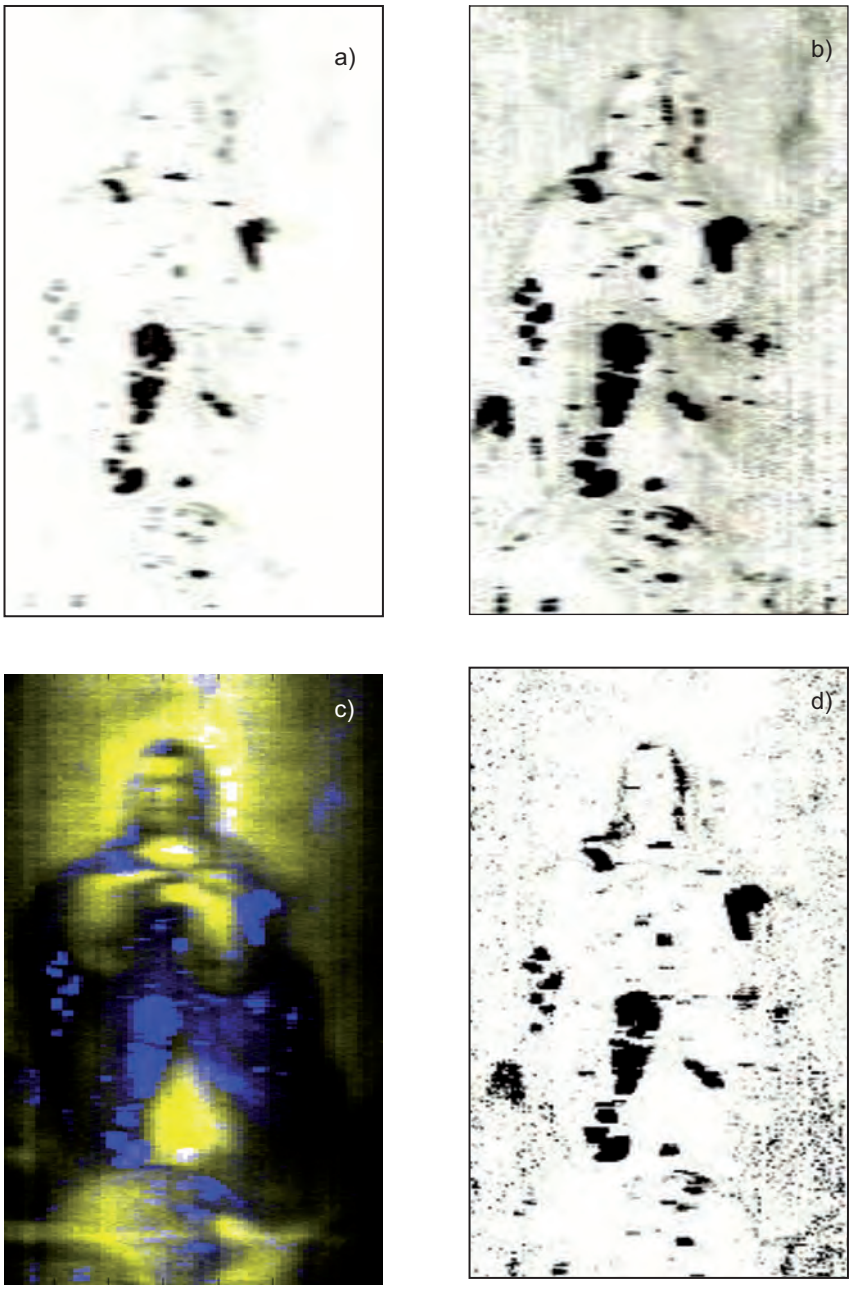


Figure 20– a) Background corrected absolute band intensity image of F360 nm band; dark areas correspond to high fluorescence intensity, b) background corrected absolute band intensity image of F360 nm band normalized to F450 nm; dark areas correspond to high intensity ratio, c) two colours image is used to better document the restoration process. Areas (presumably treated) with prominent F360 nm emission band appear in blue; grey areas are uncertain; yellow areas are minimally treated (scan # A38 spatial resolution was degraded to 2:1). d) Results similar to those of panes a) and b) are obtained by using scan A39 background corrected absolute band intensity image of F360 nm band normalized to F480 nm; dark areas correspond to high intensity ratio.

Pigment identification

As an example of pigment identification, we report in Figures 21a and 22a the application of SAM algorithm on scan# A39. Obtained results suggest that these pigments are used in a complementary way, since the first is predominantly used in areas where the second is not used.

Some exceptions can be found in the background near to the upper right corner of the image, where SAM (Spectral Angle Mapper) algorithm reveals the tiny use of blue pigment.

It is also worth noticing that despite the close similarity between the reference spectra shown in Figures 21b and 22b, the SAM is able to differentiate pretty well different colored areas.

A similar analysis done on scan A38 (not shown) results in not satisfactory results; this is explained by considering that the settings of the collecting optics for scan #A38 were optimized for UV, then the LIF signal in the 400 nm – 800 nm spectral region was noisy.

The SAM mapping was also applied to the purpose of localization of selected pigments. The analysis results shown in Figure 23 report the similarity maps computed by considering as endpoint the reference spectra of samples prepared with historical pigments and following the ancient preparation recipes. The scan A38 taken on the Glorification of Mary (*La Glorificacion de la Virgen*) has been carefully analyzed with the purpose to identify the specific spectral features inside of the scanned area. The LIF spectrum of the blackish regions (Fig. 23b) reveals spectral features similar to those of carbon black pigment with a peak in the UV region around 290 nm; it is worth noticing that the painter has probably used the black color to reinforce the outline of the mantle and other details to have a brighter and more contrasted picture.

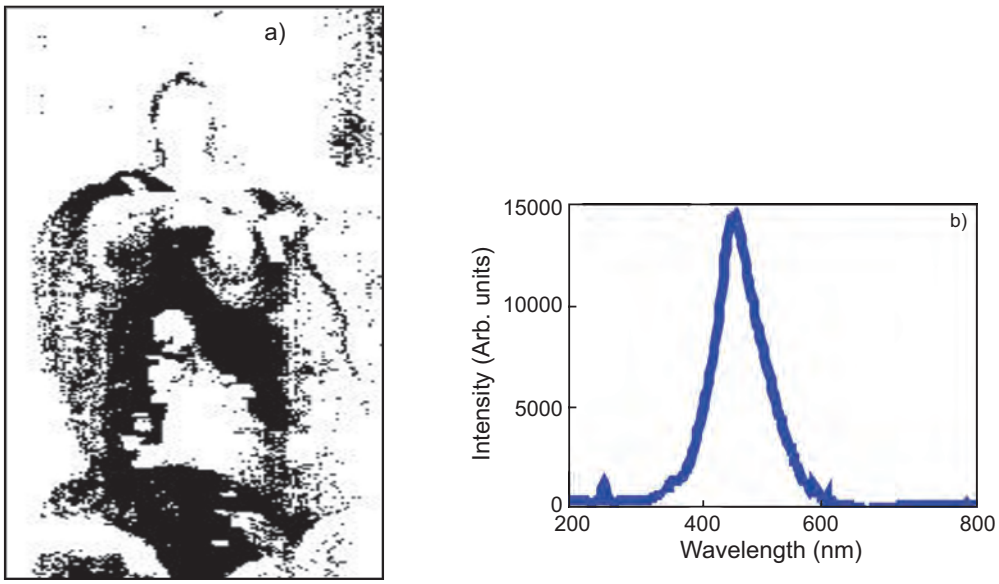


Figure 21 – a) usage and distribution of blue pigment as determined by using scan #A39 and SAM algorithm, b) reference spectrum used for SAM algorithm.

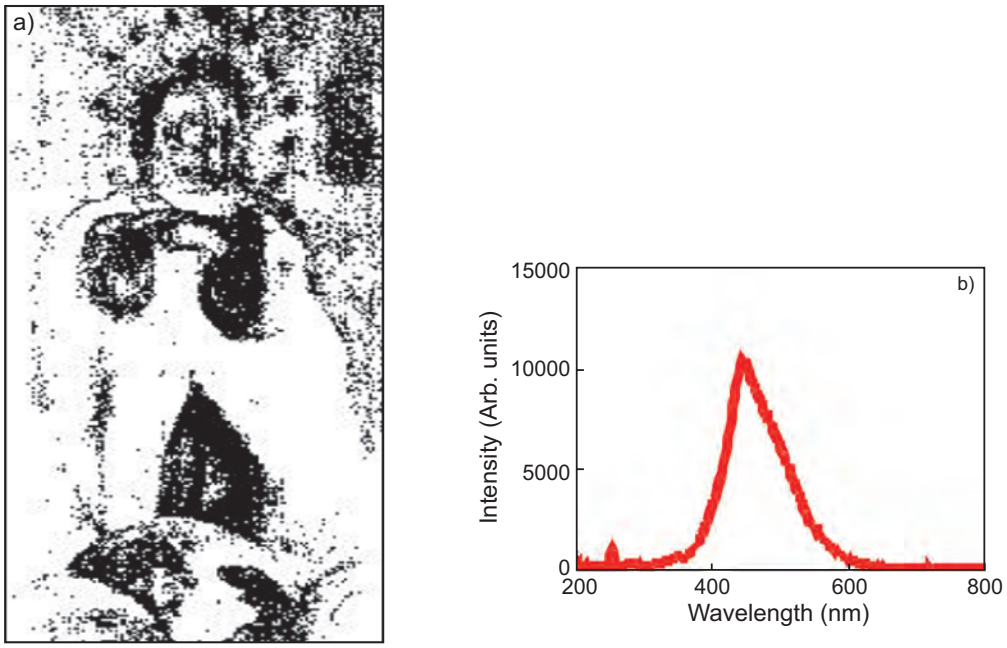


Figure 22 – a) usage and distribution of red pigment as determined by using scan #A39 and SAM algorithm, b) reference spectrum used for SAM algorithm.

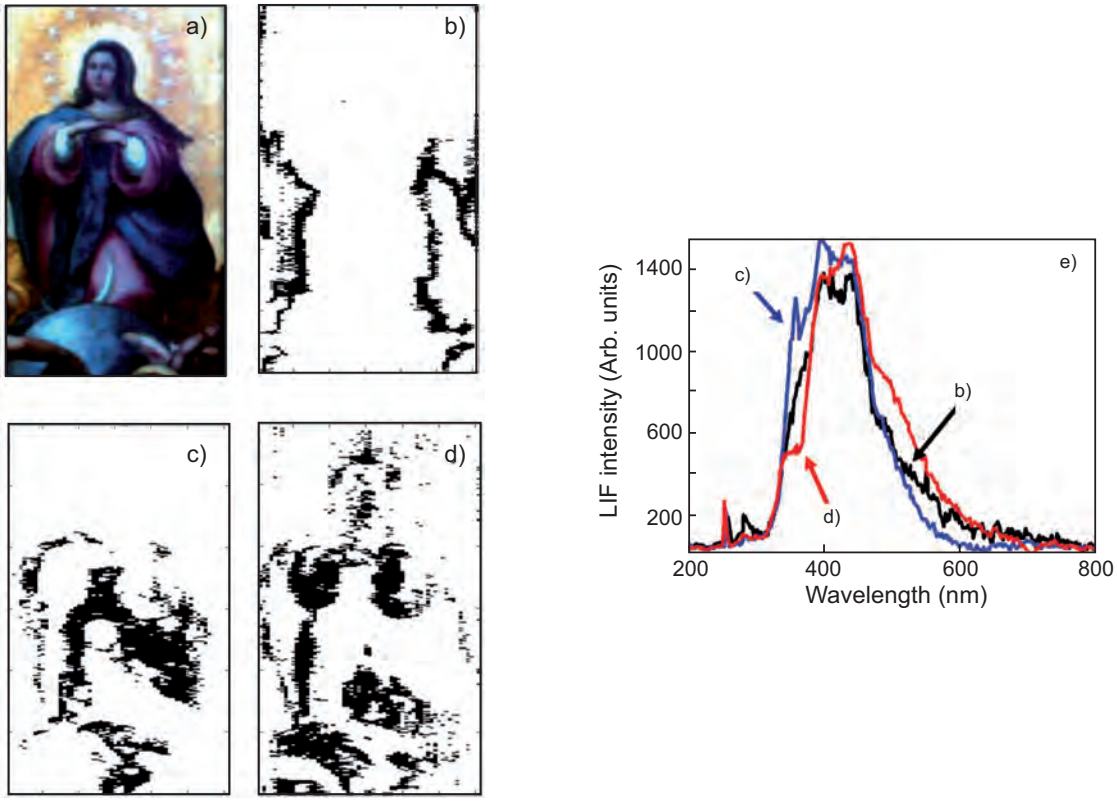


Figure 23 – Results from the application of the SAM analysis on the La Glorificacion de la Virgen fluorescence image; a) reconstructed color image, b), c) and d) similarity maps generated by considering the reference spectra shown in e)

The similarity map of Figure 23c details the use of blue pigment found in the mantle. Although fast and attractive for its simplicity of analysis, the proposed LIF analysis has some important drawbacks not to be forgiven: first of all we have to consider that some pigments characterized by efficient non radiative deexcitation pathways have a very low fluorescence yield and from a practical point of view are difficult to detect and to identify. In those cases the presence of plaster worsens the possibility of detecting such pigments, because its fluorescence makes their contribution negligible. Complementary techniques to resolve the ambiguity in the pigments' identification are necessary in these cases.

3.4 Analysis of images on small vault (A41 – A44)

The last scans in the Virgen del Buen Aire Chapel were performed on the painted portion on a small vault near the main entrance of the church. The LIF system was placed at the floor level at a distance of 3.8 m from the vault. Several experimental runs were made by optimizing the collection optic for getting UV and visible spectral ranges.

Comparison among different images' resolution

Since the optical system was operated in different focusing conditions, a couple of scans were made to check the effects due to changes of pupil entrance aperture and of the number of scanned lines. As rule of thumb we expect to have images with rich spatial resolution by using higher f# and higher number of scan lines, however low resolution and degraded image still have good spatial resolution, allowing for identification of the texture meaning.

Figure 24 shows three images taken in the conditions: a) 300 lines and F#22, b) 150 lines and F#2.8; c) the full resolution of the first image is degraded to 150 lines. Figure 24b) is the most bluned image and still retaining all relevant spatial details, here we notice the degraded appearance of the leaves in the left side and of the veil around the head of the main character (Charity).

Figure 24 – Comparison between high resolution a) and low resolution b) and c) line scans. a) image is obtained by 300 scans lines and optic acceptance f#22; b) is 150 line scans and f#3, c) is obtained by degrading the 300 line to 150 and f#22.

Fluorescent bands identification

The analysis of the PCA components, reported in Figure 25, shows the occurrence of several prominent fluorescent bands at F280 nm, F300 nm, F450 nm, F520 nm.

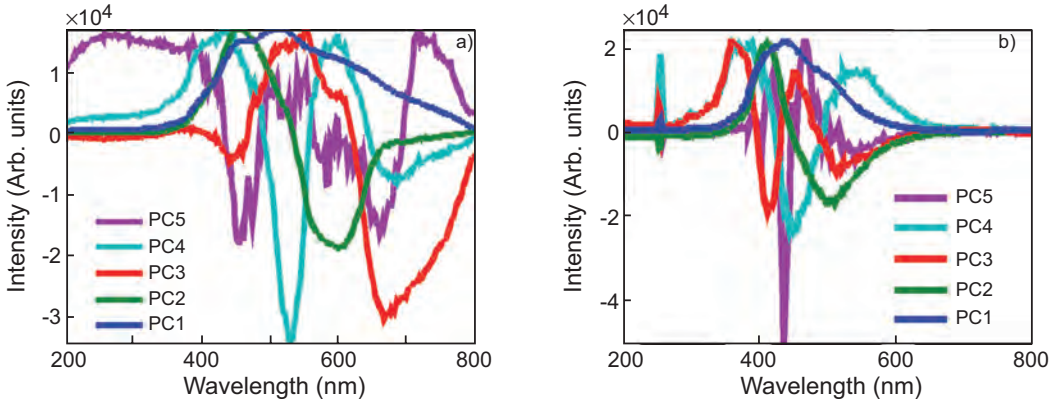


Figure 25 – PCA spectral components of images A41 upper left a), A43 upper right b), and A44 lower right c).

Identification of retouches or consolidated areas

The strong emission band at F360 nm is not well represented on the PCA components, however it is still present in very limited areas shown in Figure 26. This is a strong evidence for the fact that this artwork was subject to a different conservation/restoration process.

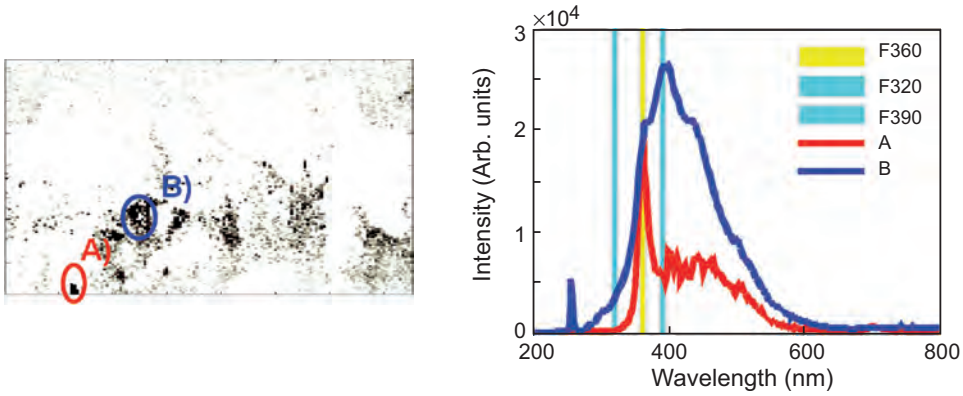


Figure 26 – B/W image with the F360 nm emission band; the image is background corrected and not normalized, (scan# A44). Areas with high fluorescence intensity are darker. On right side it is shown the plot of spectral emissions averaged in areas indicated by corresponding identifiers and colou.r

The analysis of the spectral emission at 450 nm reveals an interesting feature shown in Figure 27. Here we can observe a sort of transversal bandage crossing the entire image. A possible interpretation could be related to the technique used by the artist who prepared the background possibly with an uniform substrate daily prepared according to the historical painting technique named “giornata”.

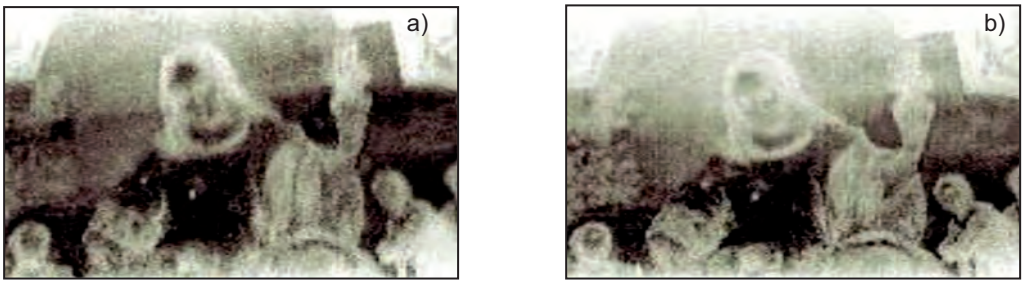


Figure 27 – a) B/W image with the F450 nm emission band; the image is background corrected and normalized to the residual of the elastic backscattering at F266, (scan# A44). Areas with high fluorescence intensity are darker. b) same data treatment on scan# A43.

4. Conclusions

The discussion of LIF images collected from the Virgen del Buen Aire Chapel fresco's first demonstrate the ability of our LIF scanning system to remotely operate on real target up to distances slightly larger than 11 m. Image processing with statistical algorithms (PCA) permitted to reveal traces of a former restoration where different consolidants were utilized: namely the distribution of a chemical characterized by a strong fluorescence emission at 360 nm, probably belonging to the paraloid group, has been obtained on two different investigated areas. Combining the information obtained from high quality reflectance images, collected as by-product from the scanning system, and a data processing based on a projection operator (SAM), it was possible to investigate original pigment (blue and red) distribution, with location of possible retouches. Spectral characteristics, related to the substrate preparation were also revealed in a third investigated area.

In conclusion, even in the absence of reference samples and suitable data bases which would allow to obtain definite identification of components and possibly quantitative data, LIF images can supply useful information to the restores relevant to formerly treated areas.

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