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# Optical coherence tomography for painting diagnostics

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## ABSTRACT

In the last few years many non-destructive techniques have entered the field of painting conservation, and most of them are routinely applied to study and monitoring the painting status. Among them optical techniques are by now widely diffused and extremely well received because of their effectiveness and safety, nevertheless none of them is suitable for a quantitative characterization of varnish. One of the most important and often controversial stages of painting restoration is the surface cleaning process up to now being carried out without any tool to measure the actual varnish thickness but microscope observation of micro-detach. In this work we present an application of Optical Coherence Tomography to non-destructive diagnostics of artwork: the potentiality of this technique is demonstrated by measuring the thickness of the varnish layer in a fragment of a nineteenth-century oil painting.

**Keywords:** optical coherence tomography, non destructive testing, painting conservation

## 1. INTRODUCTION

In the last decades science has offered a fundamental contribution to conservation of paintings and a variety of scientific investigation techniques are by now routinely applied to study actual status of works of art as an integral part of their restoration process, concerning both repair planning and monitoring the various restoration phases.

Besides the cultural or artistic value, what makes ancient paintings peculiarly worthy of special attention is their uniqueness: every object is a case-study, making difficult the working out of a conservative project. For that reason non-destructive testing techniques have seen a successful growth in last years and among them optical techniques are now widely diffused and extremely well received in the field of painting diagnostics because of their effectiveness and safety.

A painting is typically composed of a wooden or canvas support, a ground layer, one or more painted layers and a protective varnish film. Depending on the realization technique and on the restoration interventions and the traumatic events suffered, this structure can be even much more complex. At present, many optical techniques for non-destructive investigation of paintings are available, both inherent to the characterization of painting layers (IR reflectography[1,2], UV fluorescence[3], multispectral imaging[4,5], …) and finalized to 3D survey of painting's form and roughness (laser-line profilometry[6], micro-profilometry[7], …). Nevertheless none of them is suitable for a quantitative characterization of varnish, that has been done since half a century in an invasive way by detaching a micro-sample from the painting surface and investigating its stratigraphy with a microscope.

The varnish film was generally spread on the painting layer both to protect it and to make it brilliant. Ultraviolet radiation exposure, dust deposition and over-painted varnish film, all contribute to make opaque and turn dark-yellow the varnish film, this way altering the original appearance of painting polychromy. For that reason one of the most

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important and often controversial stages of painting restoration is the surface cleaning process: it usually consists in removing either the dirt layer accumulated during the years on the painting surface or, more frequently, the old matt and yellowed varnish film. From an aesthetic point of view, decisions have to be made regarding partial or complete removal of varnish and technical considerations include selection of a method that allows a great deal of control in the cleaning process, so that the desired layer can be removed without damaging the underlying one.

Optical Coherence Tomography (OCT) is a relatively new high resolution imaging technique that uses visible or infrared light to provide non invasive cross-sectional imaging of partially transparent or scattering tissue on the micrometers scale with probing depths up to 1-2 mm. Its first application in medicine is reported about ten years ago[8], since then it has been widely applied in the biomedical field for probing human eye, skin, internal organs and other biological tissues[9,10]. A few tens of microns depth-resolution imaging can be performed with standard broadband sources such as superluminescent diodes[11] while femtosecond Ti:$Al_2O_3$ laser with bandwidth of 100 nm, provide sub-10 micron resolution, making possible sub-cellular imaging[12].

An application of OCT to painting diagnostics is proposed herein for non-destructive measurements of the varnish layer thickness.

## 2. EXPERIMENTAL APPARATUS

OCT is most commonly based on the use of low coherence light sources in a Michelson-type interferometric set-up to perform coherence-domain reflectometry of tissue structure: backscattered radiation from different depth interfaces in the sample and a delayed reference field, optically interfere whenever they overlap within the radiation coherence time. Depth resolution is limited by the source coherence length and the focal spot size within the sample states transverse resolution. Cross-sectional images can be acquired by transverse scanning the probe field across the sample while subsequently scanning the reference field corresponds to scan along the axial direction (depth).

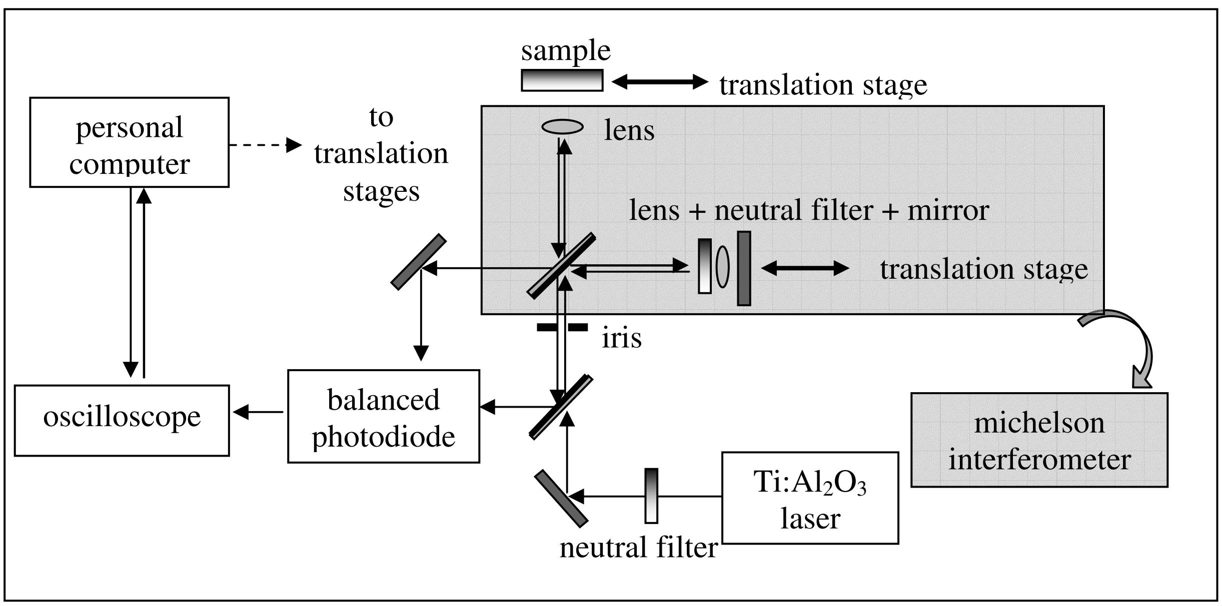


Figure 1: Experimental set-up.

The experimental set up (fig.1) is based on a Kerr-lens mode-locked Ti:$Al_2O_3$ laser source with 82-MHz repetition rate, mean output power exceeding 200 mW and 800 nm central wavelength. The compact x-shaped Ti:$Al_2O_3$ cavity is based on chirped multi-layer dielectric mirrors for dispersion control that, arranged with an highly doped Ti:$Al_2O_3$ crystal, allows the generation of ultra-short laser pulses of great quality and stability with pulse duration of about 12 fs FWHM.

Figure 2 (left hand) shows the typical spectrum of laser pulses with a FWHM bandwidth of 100 nm. On the right hand the corresponding autocorrelation signal is shown, demonstrating a depth resolution in air of 3.6μm.

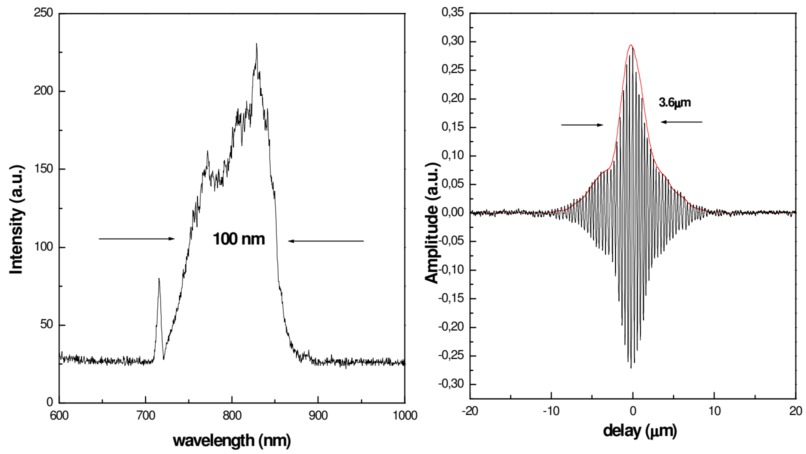


Figure 2: Typical spectrum of laser pulses (left hand) and the corresponding autocorrelation signal (right hand), demonstrating a depth resolution in air of 3.6μm.

The laser beam passes through an iris, whose aperture allows to control the focal spot size and the confocal parameter within the sample. The whole varnish extent (typically ranging from some tens of microns to a few hundreds microns) was covered with maximum transverse resolution without adjusting the focus position within the sample.
After being filtered to a mean power of 10-15 mW, laser pulses are directed toward a Michelson interferometer (Fig.1). The probe field is focused on the sample by a short focal-length lens (f =25 mm), held by an XYZ translator for focusing adjustment. Dispersion compensation is achieved by placing an identical lens and a neutral filter of appropriate thickness in the reference field path, the filter permitting also to balance the relative intensity of the two arms. All the components of the Michelson interferometer are chosen in order to obtain optimal performances at 800 nm.
The mirror on the reference arm is assembled on a motorized translation stage that allow scanning the sample in depth (Z) with a speed up to 420 micron/sec. Scanning in a transverse (X) direction is as well obtained by moving the sample with another translation stage. The difference in the signals from two photodiodes placed at the exit of the interferometer ports is then acquired while scanning the motors. Dual balanced detection cancels the dc signal and the excess noise caused by fluctuations in the source. After amplification, bandpass filtration and 8-bit analog to digital conversion, the envelope of the detected signal is extracted. By detecting the interference pattern at different transverse (X) positions of the specimen, a two-dimensional data set was generated which represents the backscattering through a cross-sectional plane of the specimen, acquired for every sweep of the optical delay line in the reference arm. The cross sectional image of the optical backscatter from within the specimen is then generated by assembling adjacent depth scans and it is visualized in a 8-bit standard image format. The whole device is computer-driven: a purpose-developed software controls both translation stages, so to automatically perform a scan in depth of the reference arm for each transversal step of the sample, as well as acquisition and data processing.

## 3. RESULTS

In order to demonstrate the capabilities of OCT for non destructive analysis of ancient painting varnish, cross sectional imaging was performed of a fragment of a nineteen-century oil painting kindly supplied by the Opificio delle Pietre Dure of Firenze.

A 2×2 $mm^2$ (XY) area of the fragment was investigated by acquiring a set of 280µm-deep 2mm-wide OCT (ZX) images with an X-sampling step of 5µm. Acquisitions were repeated every 250 µm along the Y direction, for mapping the whole investigated volume. One of the acquired images is shown in Fig.1a.
The investigated volume was then detached from the fragment and embedded in a transparent epossidic resin in the liquid state, that afterwards solidifies. The small block thus formed was polished across the XZ plane and microscope cross-sectional images were acquired at different Y depth. In Fig.2b the microscope cross-sectional image corresponding to the analyzed area of Fig.2a is shown. The superposition of the two images after proper alignment (Fig.2c) highlights the perfect agreement of the results obtained by means of the two different way of measuring.

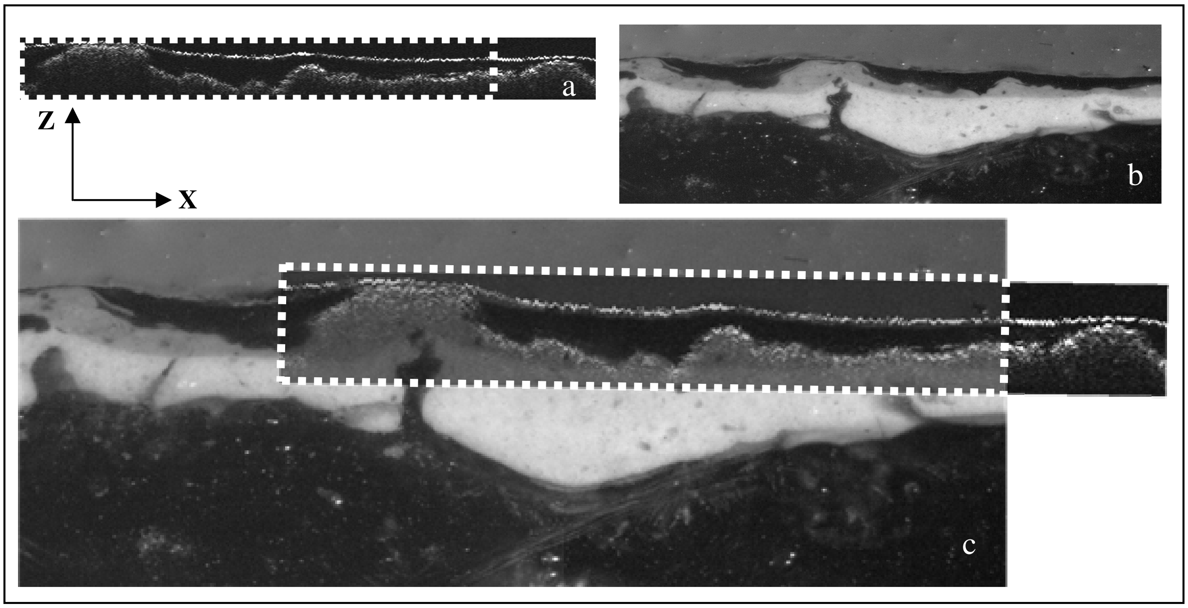


Figure 3: (a) OCT image (280µm-deep 2mm-wide) of a cross-section of the investigated volume. The varnish film surface (first from the top) and the paint layer surface are clearly visible. (b) Image of the same cross-section acquired with a microscope after detaching the investigated volume and (c) superposition of the two images.

## 4. CONCLUSIONS

We presented an application of Optical Coherence Tomography to painting diagnostics thus demonstrating the potentiality of this technique for non-destructive measurement and monitoring of the varnish layer thickness.
Cross sectional imaging was performed of a fragment of a nineteen-century oil painting kindly supplied by the Opificio delle Pietre Dure. Comparison between OCT data and microscope cross sectional images, obtained after traditional micro-sampling, were carried out.
The results show a very good agreement between the images obtained by means of the two different way of measuring.

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