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EDITORIAL

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Shedding light on the past: optical technologies applied to cultural heritage

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The United Nations in the 68th session of their General Assembly proclaimed 2015 as the International Year of Light and Light-based Technologies (IYL 2015, http://www.light2015.org) in recognition of the important role optical and photonic sciences and technologies play in so many aspects of our lives on earth in relation to key sectors such as communications, health, energy, agriculture, space and education.

On this occasion, *Heritage Science* presents a thematic series dedicated especially to "optical technologies applied to cultural heritage", which showcases representative contributions highlighting innovative research results from experts on the application of light-based technologies in cultural heritage analysis, diagnostics and conservation.

One cannot overemphasize the major role light plays in promoting our tangible heritage. Either natural or artificial, light is an "element" necessary for visualizing works of art and monuments, and in fact it determines how one perceives and interacts with such artefacts, including the artists or creators themselves. Colour and combinations of colours, variations of lighting and shade create unique impressions and feelings. The Pyramids, the Parthenon, the Mona Lisa and numerous heritage masterpieces around the world convey their message to and generate their impact on the observer via an intimate interaction with light.

But light plays an additional, very important role, yet not so profound to the average public, in promoting our understanding and knowledge about our tangible heritage through scientific studies. Indeed, photons at different frequencies, ranging from the X-rays, through the ultraviolet, visible or infrared all the way to the radiowaves region of the electromagnetic spectrum, may interact with materials and objects via a score of different processes such as absorption, scattering, emission, diffraction, refraction or interference, enabling scientists to visualize the details of key chemical and physical features in heritage artefacts and samples revealing their secrets, finding traces of their history and their making or securing their way to a safer future [1, 2].

Continuous advances in light and photonic technologies, many of them catalysed by the invention of the laser in 1962, have made available a broad set of powerful optical and spectroscopic tools, which scientists have employed in various analytical investigations aiding archaeologists, historians and conservators in their studies and practice. Prominent among these light-based technologies are the various types of spectroscopic techniques [1, 3], several of them highlighted in the present thematic series. These techniques enable identification of materials at the atomic or molecular level and through such analyses permit scientists and historians to view intimate chemical and physical details of art objects or archaeological findings and contextualize them artistically, historically or technologically.

For example, the article by Castro et al. [4] shows how careful micro-analysis of paint cross-sections, based partly on Raman spectroscopy reveals the history of objects, and maps the stratigraphy of the original paint and subsequent conservation treatments aiding the way to a proper restoration, as these researchers found out working with samples collected from the faces of the two tower clocks of the Government Palace at Helsinki (Finland). In a different perspective the article by Boyatzis et al. [5] shows how spectroscopic tools, such FT-IR/ATR spectroscopy, can be used to understand mechanistic details related to the way iron gall inks interact with parchment under artificial ageing conditions.

Clearly, the need to avoid sampling from precious or very sensitive artefacts has dictated the increasing use of non-invasive techniques that can be operated in situ, namely on an object itself, as nicely shown by Smith and co-workers, who studied pigments on selected prints

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from the Haku Maki's '*Poem*' series [6] at the Indianapolis Museum of Art (USA), or by Miliani and co-workers [7], in the study of the paint palette in Jackson Pollock's '*Alchemy*' (Peggy Guggenheim Collection, Venice, Italy). The latter work clearly shows the value of compact mobile spectrometers that enable studies to be carried out outside the research laboratory and even outdoors as also shown in the paper by Papliaka et al. [8].

Thanks to advances in light sources, optics, analysers and detectors, most spectroscopic methods are nowadays coupled to microscopes, offering spatial information that reaches high levels of detail. But while point analysis (1-D analysis) provides detailed information from a well-defined area on an object or sample, often one needs to collect data from over a larger area on the surface of an artefact in order to find distinctive patterns and possibly correlate them with materials and their spatial distribution on the object surface. In this context, imaging techniques coupled to various types of spectroscopy come out as important and enabling tools for 2D-analysis. The article by Kogou et al. [9], on the '*Selden map of China*' (early seventeenth century) from the Bodleian Library in the University of Oxford, shows an example of how imaging in the visible part of the spectrum gives rise to quick visualization of the distribution of several pigments across the surface of the map. Importantly, under favourable conditions, multi-spectral imaging permits the identification of pigments based on characteristic reflectance spectral features, as also highlighted in the study of Pollock's '*Alchemy*' by Rosi et al. [7].

When direct imaging is not possible due to various limitations, for example poor signal strength or lack of appropriate optics or detectors, surface mapping is still possible, via raster scanning approaches and this is the case, for example, with Raman, FT-IR or XRF imaging. The use of the latter is demonstrated in the study of another work by J. Pollock, '*Number 1A*' (1948) at the Museum of Modern Art in New York (USA) based on the use of macro-XRF elemental mapping for delineating the paint distribution across selected areas of the painting as shown in the paper by Martins et al. [10]. The results of the paint mapping have enabled these authors to virtually reconstruct the artist's process suggesting the sequence he followed in applying the various paints, and thus one can claim that effectively, 3D-analysis (volume analysis) with chemical information is something that can be achieved despite the complexity of these multi-layered substrates. This type of in-depth analysis is also shown in the work by Favero et al. [11] that describes a comprehensive investigation on Picasso's '*Blue Room*' (1901) from the Phillips Collection at Washington DC (USA). The painting hides a portrait of a man beneath it, which has been almost perfectly revealed by use of near infrared imaging. Detailed X-ray fluorescence imaging performed directly on the artwork, at the Cornell High Energy Synchrotron Source (Ithaca, NY, USA), aided on mapping the distribution of pigments across both the Blue Room and the underlying portrait. Following a different approach, volume information, but not with chemical specificity, can be supplied by use of techniques relying on the coherence of laser sources such as optical coherence tomography (OCT) described in the paper by Liang and co-workers [9] or holographic interferometry [12].

A fourth dimension, that of time, can be also exploited by use of pulsed laser sources which, as presented in the article by Comelli et al. [13], enable the characterization and mapping of luminescent materials not only on the basis of their emission spectra but also on the basis of the excited state lifetime of the emitting species, adding an additional parameter in the effort to distinguish and map different types of chromophores.

Considering, in a broader perspective, the use of lasers, one can easily observe several advantages offered by these special light sources, once referred to as the "*solution that looks for the problem*", hence it is no surprise that they are increasingly investigated in the context of heritage diagnostics and conservation applications [14]. Power and monochromaticity are key to the success of present day Raman spectrometers, coherence is behind OCT or holographic techniques, while pulsed sources provide the ability to exploit time-resolved phenomena, such as fluorescence (or photoluminescence) lifetime imaging, non-linear multi-photon microscopies [15] or even to propose new techniques based on laser ablation sampling, for example LIBS [8] or laser ablation mass spectrometry [16]. One of the novel applications of lasers relates to the use of the laser ablation process as a unique conservation approach that enables non-contact removal of selected layers from the surface of artworks and monuments. An example from such a research study and application in the conservation of stone sculpture in a world monument, the Acropolis of Athens, is shown in the paper by Pouli et al. [17].

As amply demonstrated through the investigations highlighted in this thematic series light-based techniques are increasingly being used in the study and conservation of heritage objects. It is clear that all of them have distinct strengths but at the same time they are not free of limitations and thus a full and meaningful investigation often calls for the use of several analytical tools in a combined approach, which depends primarily on the question or questions asked in the context of each specific study. While this is an important methodological issue, namely which tools are the most appropriate ones for obtaining materials information as complete as possible for the case in hand, it can equally well be a major technology and innovation driver considering the potential for developing hybrid instrumentation combining more than one techniques.

Finally, despite the fact that many of these techniques offer unique capabilities for illuminating secrets of historical and cultural artefacts still their use should be done with caution remembering that photon–matter interactions imply excitation of various degrees of freedom in atoms and molecules and these interactions may in turn give rise to unwanted side effects when photon energy or flux or both are exceeding certain thresholds. This is discussed, for example, in the paper by Smith and co-workers [6], who show a careful study on the colour changes of pigments induced by regular white light illumination, in an effort to establish safe illumination levels for exhibiting the prints. The same authors note the sensitivity of pigments under the focussed laser beam of a Raman spectrometer. Clearly the subject of establishing safe limits when studying works of art, monuments and even samples from heritage objects with different types of photons is an open issue, which will be receiving attention in the future [18].

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