Reflectance spectroscopy safeguards cultural assets

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Portable reflectance spectroscopy devices working in the UV, visible, and near-IR region allow non-invasive and in situ conservation assessment of artworks.

Safeguarding the future of artworks is a significant challenge for the cultural heritage (CH) sector. Among the most important considerations are preventing natural and human-caused damage to artworks on display, assessing the risk of handling and transporting important pieces, and deterring fraud. A wide array of technological solutions is on offer to meet these challenges, including an important class of optical techniques based on reflectance spectroscopy.

In recent years, the CH sector has shown a renewed interest in performing non-invasive and in situ measurements with portable reflectance spectroscopy devices that use the UV, visible, and near-IR region (UV-Vis-NIR). This trend has been driven in part by technological improvements to the devices, and also by an urgent need to study and preserve the non-traditional artistic materials used in contemporary art.

The working principle behind UV-Vis-NIR reflectance spectroscopy is to analyze the way radiation reflects off a given spot on an object’s surface to help establish its composition. Portable reflectance spectroscopy devices, as the name suggests, offer the same analytical tool in a portable setup. We use optical fibers both to guide the incoherent radiation emitted from a broadband source to our study area on the artwork, and to collect the reflected radiation and send it to a spectroanalyzer for analysis. The UV-Vis-NIR spectrum is particularly useful for establishing a painted artwork’s chemical composition, and for monitoring superficial degradation where this is accompanied by alterations to the artwork’s color. The information that these portable reflectance spectroscopy devices provide is fundamental to designing effective conservation and restoration interventions.

Moreover, the reflectance spectrum in the visible range (380–780nm) forms the basis of colorimetric analysis, which we use to evaluate the chromatic changes an artwork experiences (such as discoloration, yellowing, and darkening) and for monitoring these processes over time. Colorimetric analyses also play an important role in a class of sensors specifically developed for monitoring the museum environment. In recent decades a new generation of sensors, called impact sensors, has begun to find application in the CH field. These sensors mimic, in a simplified way, the reactions that environmental factors induce in artistic materials. For instance, the sensor might change its color in a way that can be detected either visually or through reflectance spectroscopy. By measuring this change, it is possible to assess

Continued on next page
the impact of the environmental factor on an artwork exposed to the same environmental conditions.

A notable example of the colorimetric impact sensor technology is a light dosimeter, which we helped develop under the European Commission Project Lido to monitor highly photosensitive artworks. It consists of a photosensitive dye/polymer mixture that is applied to an inert support. Upon exposure to visible light, it progressively changes color. A color reference scale helps relate the observed color to a given value of the light dose received. We performed the colorimetric calibration using reflectance spectroscopy.

From a technical point of view, UV-Vis-NIR reflectance spectroscopy may be implemented using punctual (1D) or areal (2D) techniques. For punctual techniques, the highest performance is offered by FORS (fiber-optic reflectance spectroscopy), a method specifically developed for diagnostic work on paintings. FORS was originally conceived as a non-sampling analytical technique to study immovable artworks. It was first applied in the 1980s to the Masaccio frescoes in the Brancacci Chapel in Florence. Since then, our research team has continued to improve the FORS method by designing customized probe heads to be connected to the optical fibers in order to investigate various kinds of surfaces (paintings, textiles, glasses, ceramics, and so forth), allowing the technique to be applied in the analysis of several categories of artworks.

High spectral resolution is crucial to increase the discrimination capability of the technique. We have developed a measurement protocol based on the use of a compact portable system (see Figure 1) based on two spectro analyzers (ZEISS MCS601-MCS611) and a source module (CLH600). This system ensures a spectral resolution of about 2.5nm in the visible spectrum and about 18nm in the NIR spectrum. Again, optical fibers are key to using these spectro analyzers to study artworks: an adjustable probe head connected to the optical fibers allows the user to change the pattern of illumination of the artwork (see Figure 2). Because FORS measurements can be obtained both non-invasively and quickly, statistically meaningful data are easily acquired.

The 2D version of the reflectance spectroscopy is a more sophisticated technique called hyperspectral imaging (HSI). This technique combines the features of FORS with the advantages of digital imaging. It is at the cutting edge of the technologies available for non-invasive diagnostics of polychrome surfaces. HSI involves the sequential acquisition of quasi-monochromatic reflectographic images captured over a given spectral range. As such, it simultaneously acquires both the spatial and spectral information of the imaged scene. The datafile obtained (called filecube) may be processed, either to obtain high-quality images at the different wavelengths or to generate maps that highlight materials distributions, underdrawings, and so forth. We have designed a prototype hyperspectral scanner that allows HSI to be applied to artworks. The HSI scanner we have designed has been optimized for museum applications. The optical module is designed to minimize the errors and distortions in the image that may be caused by non-planarity of ancient canvases and surface defects. Moreover, a customized illumination system, based on fiber-optic illuminators, guarantees safe conditions for the artwork, preventing excessive light exposure.

The present version of the HSI scanner operates in the 400–900nm range, and is routinely used even on valuable paintings. We have now begun a project to upgrade the scanner by extending the operational range into the NIR (900–1700nm) region. This will improve the capability of materials discrimination and possibly allow the visualization of underlying features on polychrome surfaces.

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Costanza Cucci graduated in physics and received her PhD in conservation science from the University of Florence

Continued on next page
Her research interests include non-invasive spectroscopic techniques, optical sensors, and statistical analysis. Her work has broad application in cultural heritage, environmental monitoring, and agrifood safety and quality.

Marcello Picollo has been investigating how spectroscopic techniques can be applied to artworks since 1991. His main focus is using non-invasive spectroscopic and imaging techniques to characterize artists’ materials.

References