From Spectral Images to Defensible Measurements: Control, calibration and conservation care in hyperspectral examination of cultural heritage materials

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Abstract

Hyperspectral imaging (HSI) is routinely described as non-invasive, information-rich and capable of mapping material differences across artworks. Those descriptions are incomplete. A HSI cube becomes scientific evidence only when the measurement chain is controlled well enough to distinguish object variation from variation introduced by illumination, geometry, optics, detector response, scanning, calibration, processing and time.

This paper develops a control-centred framework for optical measurements in heritage science, with particular emphasis on push-broom reflectance HSI from the ultraviolet to the short-wave infrared. It connects heritage-imaging practice with measurement-science principles and the performance characteristics formalised in IEEE Std 4001-2025. The framework treats uniformity, spectral and spatial calibration, radiometric response, signal-to-noise ratio, dynamic range, stability, mosaicking, metadata and uncertainty as coupled requirements rather than independent specifications. It also treats conservation care as part of validity: illumination must provide sufficient photons for the stated decision while minimising photochemical dose and thermal load. For multi-modal work, co-registration and data fusion are framed as measurement operations that require their own controls, rather than as purely computational post-processing. A minimum reporting checklist and protocol-level implementation guidance are provided.

The central conclusion is direct: attractive spectral maps are not self-validating. Defensible heritage measurements require a documented chain of control from the conservation question to the reported inference.

Keywords:

cultural heritage; hyperspectral imaging; reflectance imaging spectroscopy; calibration; measurement uncertainty; illumination dose; reproducibility; multi-modal data fusion