CSIS - Concierge Spectral Imaging Service

Museums and other large repositories of high value art have a need to scientifically analyze and visually capture images of their artwork in order to identify, authenticate, document, analyze, reproduce, protect, conserve and restore pieces in their collections. They currently use an array of software tools and unintegrated, manually operated generic instruments and cameras to satisfy this need. By contrast, the *Concierge Spectral Imaging Service, CSIS,* uses proprietary Spectral Masters, Inc. (SMI) technology and an integrated, automated instrument to accomplish the analysis and capture tasks faster, at less cost and with far greater range, precision and accuracy than current methods and devices. SMI packages and markets its technology as an upscale service so museums and related institutions can expense the system rather than depreciate a hardware purchase, thereby getting the benefit of a million dollar plus technology despite having capital budgets for technology that may be orders of magnitude less.

At the heart of the *CSIS* method to automatically capture high resolution art object spectra from the X-Ray bands through the IR bands is a group of United States patents protecting a superior, scientifically significant, visual imaging technology. By *International Commission on Illumination* (*Commission Internationale de l'Eclairage, CIE*) standards, the international scientific sanctioning body tasked with defining how visible light is measured and perceived, SMI technology is more complete, accurate and precise than any other color or visible wavelength image capture method or technology. This includes all currently available commercial video, digital, analog and film image capture and scanning systems.

The standard *CSIS* includes installing a containerized version of our proprietary, large format, high spatial resolution, broadband *Spectral Scanner*, with operating staff, at a client specified venue. Besides the onsite operator, clients have access to SMI's staff scientists, PhD level specialists in materials and imaging, and a support staff trained to analyze artistic style and track object provenance. Optional extras include modules to expand the live scanning area to tens of meters and also scan in 3D.

The problem *CSIS* solves

There is a lack of analytical methodology and related technology to spectrally sample an entire painting or other work of art at the necessary high spatial and broad spectral bandpasses and resolutions required to properly accomplish the task. According to the National Gallery of Art, as posited by Delaney, Walmsley and Berrie, before the National Academy of Sciences *Sackler* Colloquium, *Scientific Examination of Art: Modern Techniques in Conservation and Analysis,* the lack is "problematic" and a solution is "beyond the resources of museum conservation laboratories."

CSIS is the solution to the missing methodology and technology. Based on the needs of museums, *CSIS* adopted the *CIE* protocols as its primary scientific standard and this standard, in turn, defines and establishes apparatus requirements. *CIE* protocols therefore establish the otherwise missing analytical methodology sought by the National Gallery and also dictate acceptable equipment and technology. Consequently, CIE standards forged the design of the *CSIS* technology and created the business opportunity. Practically, by using a known scientific analytical methodology as the basis of its protocols, *CSIS* systems generate only scientifically valid data, and that data becomes the information "gold standard" for museum conservators.

A significant benefit to adopting *CSIS* methodology and technology is the enormous boost to productivity for museum staffs. Prior to the introduction of *CSIS*, museums and their conservation staffs were trained to expect and comfortable using off-the-shelf, unintegrated, generic instruments, operated in single-specimen-at-a-time measurement mode. While convenient and understood by museums, this outdated methodology and technology is highly inefficient and severely restricts scientific productivity and analysis. Assuming a motivated worker could make one unique scientific measurement per minute using a traditional microscopic, X-Ray, UV, Visible or IR instrument, productivity for this worker would top out at about 480 measurements per day. *CSIS* can produce that number of measurements in under a millisecond, without the need to involve museum staffers. Consequently, *CSIS* increases museum staff productivity because the time and manual drudgery of making measurements is eliminated, allowing staff to concentrate solely on data analysis, not data capture. Because of this mechanical and intellectual productivity boost, museum workers using *CSIS* will transition to purely analytical roles and will no longer be responsible for gathering data.

This opens the way for a new workflow at museums, where all objects can be systematically scanned spectrally and the resulting data is used by the conservation departments for traditional scientific analysis. Further, this data can also be repurposed and used in new and unique ways, yet to be discovered, by various other museum departments, or sold to organizations and individuals not associated with the museum. For example, spectral data regarding stimulus color and material composition from a painting can be paired with microscopic analysis of the painting's brush strokes to create a standardized authenticity profile that can be used to establish the bona fides of a work of art.

The scientifically based *CSIS* protocols, procedures and information formats used to organize and display data representing the spectra of art objects resolve the problem of the missing methodology, as *CSIS* apparatus resolves the problem of the missing technology. Therefore, the *CSIS* integrated solution solves old issues once thought to be "problematic" and "beyond the resources of museum conservation laboratories," and offers exciting new possibilities for museums to use, analyze and repurpose a vast new source of information about their collections.

Methodology

CSIS differs from other imaging and material analysis solutions offered to museums because its underlying methodology is an integrated solution based upon a highly specialized scientific standard. *CIE* protocols are special because the *CIE* scientific standard defines human color perception, the most important human sense when it comes to evaluating art, and the *CIE* protocols are compatible with other scientific standards associated with non-visible wavelengths. There is no other standard that so elegantly links human visual perception with other accepted scientific methods, making it the ideal standard upon which to base a system that both visualizes and materially analyzes art objects.

The *CIE* protocols establish physical standards regarding visible spectra bandwidths and imply spatial resolutions. By extrapolating the *CIE* defined spectra and implied spatial resolutions into the non-visible wavelength bands and then creating an integrated hardware scanning and imaging technology designed to operate according to the standards, *CSIS* becomes a complete, scientifically valid system for imaging and analyzing high value art work.

With critical technical specifications set by *CIE* methodology, a software infrastructure built upon a commercially available data base is used to facilitate the capture, storage, display, organization, visualization and communication of the vast amounts of spectra data the system generates, over five terabytes per standard production shift. Fronting the database is an interactive user interface available to clients and a "read and display only," free-to-the-public spectra visualizer.

By providing museums with sophisticated data structures linked to an underlying scientific standard based upon a reproducible model of human color perception, *CSIS* becomes a complete methodology for museums. The methodology establishes primary analytical standards and data formats, sets critical spectral and spatial resolutions with regards to art object analysis, and insures flexibility to revise and upgrade the methodology should newer standards, based upon advances in technology, become available.

Technology

Broadly, the *CSIS* imaging and analytical solution uses a micron-incremented, three dimensional-capable mechanical motion system to rapidly "fly" or position interchangeable *sensors, light sources and instruments* over or around art objects placed on a 4x8 foot dimensioned targeting table.

Utilizing rack mounted computers, custom apparatus and a patented, CIE-compliant methodology based upon spectrophotometry, a physics discipline, and colorimetry, a scientific engineering discipline, the scanner generates, records, transforms and analyzes the various intensity levels and wavelengths of electromagnetic energy it reflects off or transmits through the art object being imaged or analyzed.

CSIS operates in four general wavelength bands, X-Ray, Ultraviolet, or UV, Visible, or VIS, and Infrared, or IR. When imaging a work of art, the device uses an area sensor to continuously gather data from a multitude of micron dimensioned pixels within one or two of the wavelength bands during a single pass over the object. When performing non-destructive materials analysis, a single pixel or small group of micron-dimensioned pixels is usually processed and then the sensor and its *light* source is precisely and automatically moved to the next object location.

Besides integrating and automating the hardware and software associated with spectrophotometry and colorimetry, SMI's patented technology significantly advances the state of the analytical art by creating the first improvement to capturing *natural* color images since James Clark Maxwell used specially prepared photographic lantern slides projected through *primary*-colored optical filters in London in 1861 to create the first mechanical, naturally colored picture. Maxwell demonstrated the trichromatic process, the basis of virtually all current methods of capturing and reproducing color. The process is described as *Device Dependent Color*, *DDC.*

Understanding *DDC* and why it is not an acceptable process for museum conservators is key to understanding the significance of *CSIS* and why it is the acceptable solution for museums. Maxwell cleverly deduced humans could be visually tricked into perceiving an image was in natural color by using the inherently varying density of exposed photographic film to modify the intensity of light as it passed through both the film and his special primary filters during the capture and reproduction of the image. Although Maxwell used varying intensities of light to create his perceptions, he did not actually measure the intensity of the light he used in his optical illusion. Because there is no reproducible measurement, what Maxwell demonstrated was not a scientific process, despite the fact Maxwell was the greatest scientist of his time.

Underpinning Maxwell's *DDC* is a mathematical model that takes one of two complementary forms, *additive*, or RGB, the model associated with cameras and displays, and *subtractive*, or CMYK, the model associated with printers. In practice either form of the model, a nominally three dimensional coordinate system that locates a color in a *color space* using three integer values, describes how a device mixes relative amounts of primaries to produce a physical or visual *stimulus* that causes a human to perceive it as the desired color. And therein lies the critical technical difference between *CSIS* technology and Maxwell: *the integer DDC values associated with the stimulus do not represent a measurement of the stimulus, only a recipe telling a specific device how to mix specific amounts of specific primaries to create a visual or physical stimulus that triggers a perception of the stimulus*. As opposed to creating integer values needed to recreate the *stimulus*, *CSIS* technology makes a reproducible measurement of the spectra reflected off or transmitted by the *stimulus*. The Maxwell *DDC* model is called *device dependent* because the coordinates generated by the process are always unique for each device and any "measurement" made by the device cannot be exactly reproduced at a different location without using the actual primary filters from the original device.

From a scientific point of view, *DDC* has three insurmountable limitations: first, a particular combination of RGB or CMYK primary values displayed or printed on one device can appear differently on another. Second, RGB and CMYK devices are incapable of generating each other's complete color set. Third, because RGB and CMYK are subsets of the "gamut of color," or total range of hues humans can perceive visually, no conventional imaging device can capture or generate all colors perceptible to the human eye. It is impossible for software to compensate for any these inherent and fundamental limitations. Despite critical scientific shortcomings, *DDC* is commercially important because it allows for mechanical reproduction of color stimulus viewers term pleasing, rather than allowing for the accurate measurement of the *spectra* of the *stimulus*. However, because values produced by a *DDC* system are not reproducible measurement of spectra, they are of limited worth to a museum conservator trying to make scientifically valid observations and notations.

To understand how *CSIS* improved on Maxwell, you need to understand the physics and psychology of color. *Color is an aspect of human sensory perception, not an attribute of an object*, and it is triggered when a portion of the electromagnetic spectrum, commonly called light, is reflected off an object and absorbed by physical receptors in the eye, causing the optic nerve to send signals to the visual cortex of the brain and elsewhere, where the signals combine with memories and are interpreted as sight. Color is an intuitive, *psychophysical* phenomenon that can be ordered and compared but it cannot be measured.

However, the intensity of the many varied wavelengths of light reflected off an object, *the spectra of the stimulus*, can be measured. And knowing an object's spectral profile allows us to understand and note mathematically how a human perceives the color of the object, not how a device produces a colorant that "dyes" the object a hoped for, humanly perceptible hue. Making this measurement very fast, very precisely and over a broad spatial area while storing and mathematically transforming the measurement in real-time according to *CIE* standards is the technical advancement *CSIS* claims and its patents protect. The captured spectra are compatible with scientific standards, spectral measurements made in the non-visible electromagnetic energy bands and, of course, all the measurements are reproducible. Further, the values generated by *CSIS* can be transformed into *DDC* color values that can be optimized for a specific device such as a monitor or printer. This optimization is another significant advantage of the *CSIS* system. By knowing exactly how a human perceives a color stimulus and the absolute limits of a *DDC* system, the data generated by *CSIS* may be mathematically transformed into *DDC* values tailored to a specific device, thereby most effectively and precisely using the output and display capabilities of a specific *DDC* system to simulate the actual perceived colors of the object in question.

The process of capturing visible spectra and transforming it according to standards published by the CIE is called *Device Independent Color*, *DIC*. We call a digital file processed in this manner a *Spectral Master*. Significantly, SMI is the only vendor of imaging technology to follow this complex and demanding protocol. And it is why SMI technology is advancement over Maxwell and superior to the commercially available *DDC* systems.

The Spectral Masters imaging technology is the only method that complies with all international color standards recognized by both the scientific and industrial communities, including CIE Publication 15.2, ISO 10526 and 10527, ASTM E308 and E1164, ANSI CGATS.5-1993 and IT8.8-1993, and ICC 1:1998-09. The system is also consistent with current industry trade standards, such as Apple's color management system ColorSync, Microsoft's color management system ICM, and Adobe's TIFF image file format, making Spectral Masters' CIELAB-encoded files compatible with PCs, MACs, Unix and Linux systems and such important software systems as Adobe's PhotoShop.

Therefore, by integrating Spectral Masters' patented, visible light imaging technology and methodology with apparatus optimized to capture and analyze non-visible segments of the electromagnetic spectrum, it is possible to create a device that systematically and uniformly analyzes artwork using the broadest segment of spectra possible to reveal physical and esthetic properties of an original work of art that can or cannot be visually seen or recorded.

Intellectual property

Spectral Masters technology uses hyperspectral apparatus integrated with a digital transformation engine to conform to CIE human color perception measurement and notation methodology. The Patent and Trademark Office has granted patents for hyperspectral apparatus used in the unrelated fields of space and airborne remote sensing, as well as in medical diagnostics. This demonstrates that patent protection is available for novel uses of hyperspectral apparatus as well as the apparatus itself. Therefore, on March 16, 2001 Spectral Masters, via its CEO Larry Kleiman, applied for a provisional patent to protect the proprietary apparatus and process and was issued patent pending Serial No. 60/276,079. On October 31, 2002 the utility version of the application was published under the title, "Hyperspectral System for Capturing Graphical Images," Pub. No.: US 2002/0159098 A1. A total of 29 claims were made.

On August 3, 2004, US patent number 6,771,400 B2 was issued for a "Hyperspectral System for Capturing Graphical Images," and all 29 claims were allowed.

On January 9, 2003 a provisional patent application was filed for a second spectral scanner design under the title, "System for Capturing Graphical Images Using Hyperspectral Illumination." Patent Pending Serial Number 60/438,909 was issued.

On September 1, 2009, US patent number 7,583,419 B2 was issued for a "System for Capturing Graphical Images Using Hyperspectral Illumination" with a total of 28 allowed claims.

On February 8, 2011 two more patents, 7,884,968 and 7,884,980, were issued, both "wraparounds" to 7,583,419, with eight additional claims protecting calibration and transformation methods.

Future patent applications for improvements and new products, including the design of the *Concierge Scanner*, are currently in the works. This will create further intellectual property rights covering broad areas of the hyperspectral imaging application, making uncontrolled competition more difficult. Spectral Masters has no reliance on any third party intellectual property to achieve commercial success.