CRISATEL : High Definition Spectral Digital Imaging of Paintings with Simulation of Varnish Removal

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Abstract

An ultra-high definition multi-spectral scanner (from ultra-violet to infra-red) with an homogeneous lighting system is being developed for the direct fast capture of images of paintings. The multi-spectral images are calibrated using the CRISATEL pigment colour charts designed specifically for painting materials. Spectrometric analysis of the varnish layers allows the effect of aged or glossy varnish to be corrected on the digital image. Simulation of varnish removal and comparison between the simulated image and measurements made on the restored paintings will assist the curator by allowing the effect of the restoration to be previewed before taking decision. Accurate colour images and life size X-radiographs can be printed on to help the restorer and for exhibition as surrogates of fragile works of art.

Keywords

painting, multi-spectral scanner, linear lighting, pigmented colour chart, varnish measurement, optical spectrometry, simulation of varnish removal, calibrated large size printing

Introduction

Museums conserve a large number of cultural treasures which are unique, reflect our common history, and represent steps in the evolution of art. Consequently, museum laboratories not only have a duty to acquire and to safeguard scientific knowledge about these works of art by means of examination and analysis, but also to develop technologies to preserve the materials of which these works are composed. IT-based techniques, such as digitisation, image processing, data management and data protection can contribute greatly. However, there is a lack of systems and techniques to support museum activities in high-quality image capture and storage, and no suitable 'open source' management software.

The CRISATEL project (1) will contribute to solving this lack, by addressing fine art professionals as primary end-users. The project will open a new field of expertise in museums laboratories for:

- curators, art historians and scientists, by assisting them in the preservation, restoration and research of works of art , in the preparation of exhibitions, or in authentication by image-based content recognition (2) and (3):
- conservators and restorers for on-line examination of high-quality technical documents;
- students in art history, restoration and the graphic arts, by giving applied training with scientific documents and reports. A Web-based multi-lingual electronic handbook will be produced for education, learning and training;
- editors of electronic cultural products, web-site designers, and art newspaper publishers, by contributing a new kind of high-quality and high-definition electronic image.

Objectives
A set of complementary hardware and software systems will be developed that will be presented at the next ICOM-CC meeting; these will address image acquisition and image processing for colour correction. Access to the original colour under the varnish layer and the relief of the paint layer are significant scientific progresses in art research. The long-term conservation of the original state of paintings requires high-quality spectral digital imaging combined with 3D technologies. The on-line and off-line storage and archiving on magnetic or optical disk must also address the questions of durable media and accessibility at any time.

Results
High-quality digitised documents bring source material to a new research area based on image content retrieval (2). Large-scale reproductions on paper, plastic and textile open to the public and to experts, an accurate representation of exceptional documents. The production of high quality calibration charts, whose materials will be as close as possible to the pigments used by artists, ensures a common standard for museum laboratory specialists in image colour correction. Direct digitisation is about to replace photography for technical documentation at the upper end of the quality spectrum and in various scientific applications. A Web-based multi-lingual electronic handbook will help training in the interpretation of the content of technical digital images.

A new Process for non-destructive Lighting of Canvas Paintings
High speed and high definition digital capture needs intense and uniform lighting (close to one million lux) limited to the area viewed by the CCD array of the scanner. As the lighting system has to comply with current museum standards in the matter of maximum admissible light exposure for art works (a painting should not be lit continuously at 300 lux or above to avoid damage) and as available projectors cannot provide uniform lighting at one million lux, a new process for non-destructive lighting of easel paintings has been developed.
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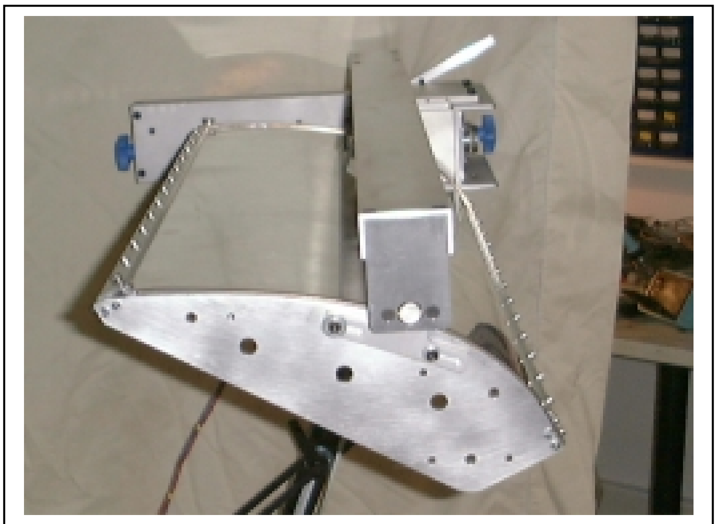

fig. 1 : the linear beam lighting system Jumbolux

The Jumbolux linear beam lighting system (see fig. 1) developed by Lumière Technologie meets these conditions. Four HQI lamps (metal halides lights, see fig. 2) with an electronic stabiliser, set at the focal point of an elliptical mirror, project a 5 cm by 3 metres line beam at 2 metres distance, producing a uniform light of one million lux . The projector is motorised and the beam movement is synchronised by a computer with the scanner moving the CCD array in the associated camera. The linear light beam produces a spatially homogeneous light on the painting which is constant throughout the time of the scan; the beam passes over each area of the painting for 3ms, reducing the exposure of any given area to the intense light from the projector. The residual spatial inhomogeneity is corrected by software with the capture of a specific non-glossy white board in the same position as the painting.

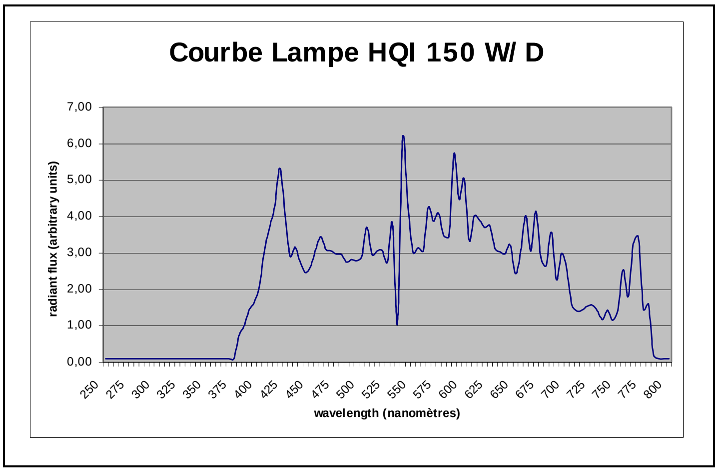

fig. 2 spectral emission of the H.Q.I. lamp

This process preserves the painting from damage caused by constant lighting when using a CCD matrix detector. The advantages of the linear beam lighting process are:

- the speed of movement of the CCD array increases with the intensity of the lighting, consequently exposure time decreases. Jumboscan needs 18s to scan a painting of 1 x 1 metre with a linear lighting system delivering 12 000 lux;
- the quality of the digital image increases with the intensity of the lighting (less parasites?? dots?? in the image, a better calculation of uniformity correction, more details in the dark areas, as well as the bright areas of the image, closing the aperture of the lens gives a more define image with a better depth focus and less effect from the environmental light);
- the quality of the digital image increases with the homogeneity of the linear lighting;
- the contrast of the digital image increases by reducing the dazzle of the lens,
- the operator can follow the scan processing (see fig. 3)

fig. 3 : two Jumbolux linear beam lights operating synchronically with the camera

The Jumboscan High Definition Digital Scanner
The definition of the digital image is limited to the size of the scanner sensor. Following the linear beam lighting system adopted for technical reasons, a CCD linear array of 12000 square pixels of 6.5µm x 6.5µm, with no inter-pixel space, has been selected for the scanner. It generates an image definition up to 12 000 pixels by 30 000 lines per scan, with a dynamic range of 12 bits. The sensor is moved across in the focal plane with a traction screw on ball bearings rotated by a motor of 50 000 micro-steps per revolution with a mechanical precision of 12µm and a repeatability of 3µm in the CCD positioning.

The scan speed depends on the quantity of light produced by the lighting source and on the camera aperture. The speed ranges between 1.3 ms and 256 ms per line, adjustable by step of 0.001 ms. The CRISATEL scanner generally captures in 3 minutes a 30 000 x 12 000 digital image.

Optical lenses are interchangeable with a focal distance ranges between 150mm and 350mm. The lens positioning is motor driven with a precision of +- 4/100 mm for a maximum displacement of 100 mm. The image scale factor is also adjustable, the camera body being motor driven with a precision of +/- 4/100 mm for a maximum displacement of 70 mm.
The camera stands on a tripod (see fig. 4) or mounting rail in a controlled environment as a laboratory or photo studio.

fig. 4 : the Jumboscan high definition camera

As 90% of paintings in museums are smaller than 1 x 1 metre, a 12 000 x 30 000 digital image gives a resolution of 30 dots/mm for a painting of this size, which fits with the resolution of large size printer. If necessary, for small paintings or small areas on large paintings, the resolution can be up to 100 dots/mm.

The CRISATEL multi-spectral scanner
The multi-spectral digitisation of paintings began, in 1989, at the National Gallery in the context of the VASARI project (4) A new type of direct capture camera based on a wider selection of multi-spectral filters will be developed in the framework of the CRISATEL project. For this project, the spectral capture processes 7 to 12 spectral bands in the visible range (400 to 700 nm) and 5 spectral bands in UV and IR, in order to perform a spectrometric colour correction.
In the visible region, band-pass dichroic blocking filters with a bandwidth of 40 +- 8nm have been chosen. Because of their acceptance angle, the filters are placed on slots in a barrel. Their bandwidth and maximum transmittance have been carefully chosen (see fig. 5). The scan speed is adjustable to control precisely the CCD exposure for every filter, in order to optimise the dynamic range of the signal. Furthermore, empty filter slots will be kept for one panchromatic filter and three RGB filters for fast digital capture. The limit of the colour space of the Lumière Technology camera derives from the choice of these filters.

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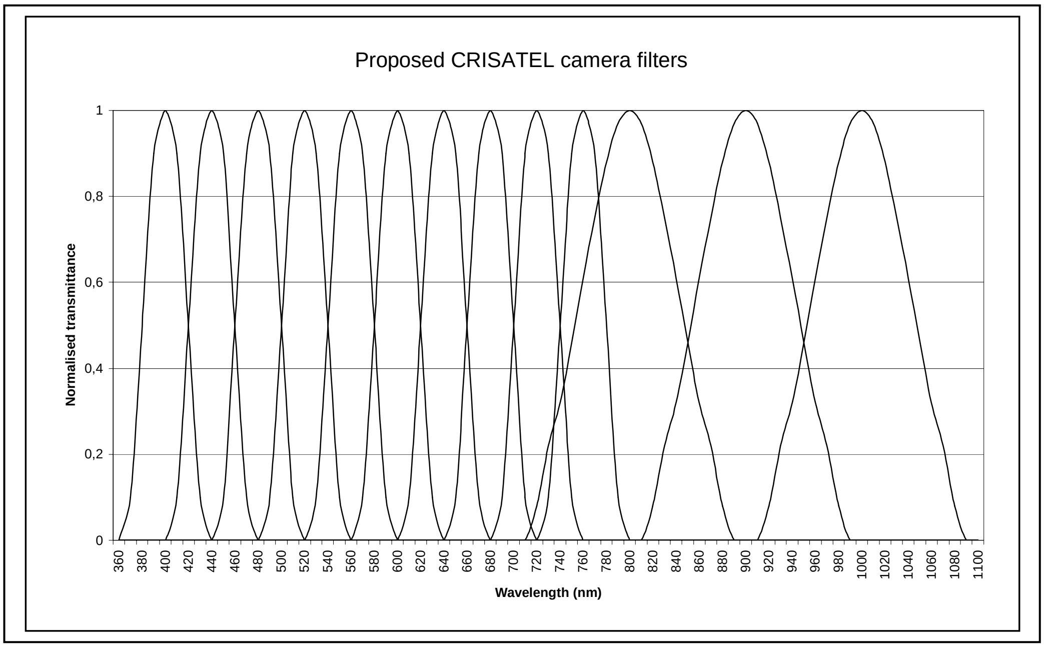

fig. 5 : scheme of the band-pass dichroïc blocking filters

Developing a pigmented chart for painting colour multi-spectral correction of colour
Available charts are not convenient because some are composed of colour patches containing mixtures of dyes with non-continuous spectra (IT8) or by a limited number of matt patches made of stable organic pigments with continuous spectra (Macbeth) (5). Consequently, a set of charts for image colour calibration and varnish thickness measurement will be produced.

An extensive study of pigments, media and varnishes gives the range of materials that can be expected in paintings such as pigments, mediums, extenders, and varnishes (6), (7).

- *The effect of pigments on colour*
The main factor that determines the gamut is the range of pigment colours in paintings. The smaller the pigment particle is, the greater the proportion of scatter compared to absorption, reducing saturation and increasing lightness. The test colour charts might include pigments ground to different particle size ranges. The CRISATEL camera can detect all pigments, with the exception of those that show fluorescence.

- *The effect of medium on colour*
The medium has a lesser effect, which is largely dependent on the ratio of the refractive indices of the medium and pigment. A closer match in the refractive index generally results in a more saturated colour. Of common binding media, oil tends to have the highest refractive index, so that when considering the boundary gamut of saturated colours, it is best to define this in terms of the gamut of pigments in oil medium.

- *The effect of varnish on colour*
Generally, the varnish serves to reduce the difference in refractive index between the paint layer and the surrounding air. This has the effect of saturating the colours further, particularly noticeable if the pigments are themselves bound in a medium that has a lower refractive index (e.g. egg tempera). It also changes the surface properties of the paint layer in terms of gloss. Under some lighting conditions, the colour appears desaturated, as the specular reflection

contributes to the reflected light from the coloured material. This can also accentuate the surface texture of the paint layer.

Two coloured charts will be produced (see fig.6): one bound with oil and one with a glossy acrylic medium. Each A4 chart will be divided into three areas containing identical pigment patches: (a) unvarnished, (b) finished with a low-gloss varnish, and (c) finished with a high gloss varnish. Each area will contain a 20-step greyscale, and up to 80 patches of pigment, perhaps including gold or silver foils to account for paintings with gilding.

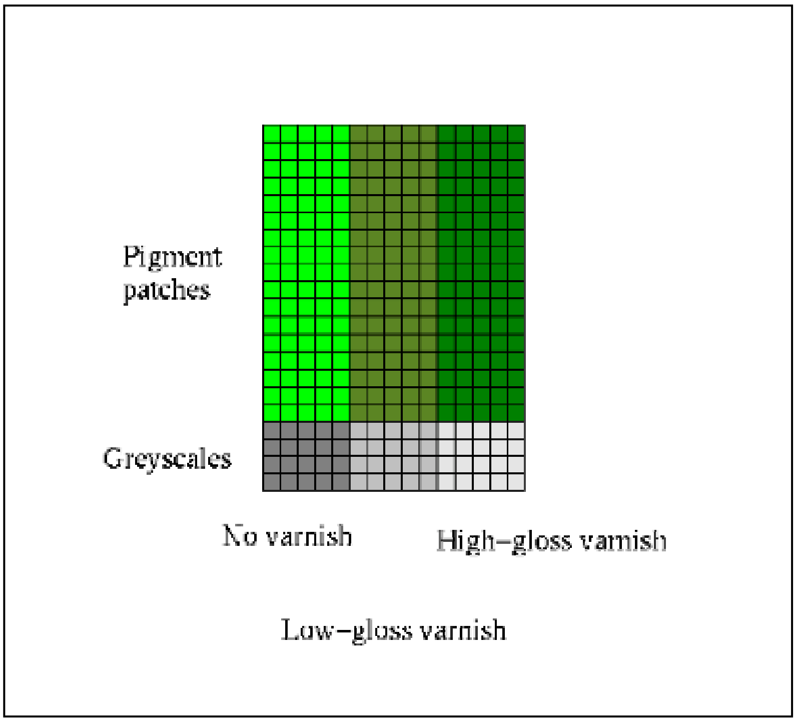

Fig. 6 : the structure of the CRISATEL colour chart

The A4 format will be convenient for most of paintings, because it can be captured alongside the work of art. . The size of the coloured patches should be no less than 13 mm, so that they can be measured with various spectrophotometers or colorimeters. This number of patches is compatible with the time dedicated to computer colour analysis. The support of the coloured patches has to be rigid, solid, flat (without texture) and neutral to the paintings components (ie it must not degas harmful substances). A test colour chart will be made on canvas to investigate the effect of texture on colour in a later experiment.

One varnish chart will contain different categories of glossy or matt varnishes (oil, acrylic or vinylic) with various regular deposits of known thickness made in one or more different isotropic layers to be measured by optical methods.

A 2600d Minolta spectrocolorimeter used for calibrating the colour charts, can produce data relating to the colour of the sample under conditions where specular reflection (gloss) is either excluded (SCE, specular component excluded) or included (SCI). This allows the amount of gloss to be determined for a sample. It is also possible to determine the effect on the colour of including or excluding the UV component of the illumination from the xenon flash in the 2600d meter. This is useful for examining the fluorescence of samples.

Varnish Opacity, Thickness and Colour Measurement
After identifying the various strata of the varnish, the thicknesses of the varnish layers are measured. The physical light absorption and scattering properties of the painting varnish layer are identified in the visible range of the spectrum by spectroscopic ellipsometry (8).
Three steps will be developed toward this end:
- spot monochromatic analysis
- spectroscopic measurements on spots
- scanning spectroscopic measurements

Other non-contact techniques, such as confocal microscopy, photo-deflection and laser induced photo-acoustic spectroscopy can also be used. Experiments will be made with the thin multi-layers of varnish in the samples prepared by Pébéo using different varnish components and thicknesses.

Experimentation at the Thomas Henry museum in Cherbourg
As the Thomas Henry museum is closed for renovation, digital image acquisition experiments are planned to test the direct high-definition digital capture of paintings with the Jumboscan and Jumbolux equipment. In 2001, 119 paintings, (30 of which are by Jean-François Millet), were scanned in three days using the Macbeth chart for colour correction (see fig. 7). Digitisation of the same paintings will be repeated in 2002, using the multi-spectral camera and the Pébéo colour charts to compare the difference in image quality. Some areas of the paint layer will be measured by spectrocolorimetry.and 3D images of the paint layers of the Millet's paintings have been acquired with a Minolta 900 laser scanner. The advantages of these combined technologies are a continuous colour reproduction of the details of object, the measurement of its relief (with which to compare painting features), and a safeguarding of its state of conservation.

fig. 7 : general view of the painting digitisation operating system at Cherbourg

Conclusion
Access to the original colour under the varnish layer will represent a significant scientific progress in art research. The high-resolution technology will help conservation in general, and contribute to the restoration management of works of art. The possiblity to assess the state of conservation of a painting at ultra-high definition and the simulated image of a cleaned painting before its restoration will assist the curator in decision-making.
High quality documents will bring source material to a new research area based on image content retrieval. The large-scale reproduction on paper and silk will bring to the public and to

experts, an accurate representation of the true colour. By making a high quality calibration charts whose components will be as close as possible to the pigments used by artists, a common standard for museum laboratory specialists in image colour correction will be established. Direct digitisation is about to replace photography for high quality reproduction and for scientific purposes.

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