PICS 5th SYMPOSIUM
May Wednesday 14th – 1 :30 PM - Track 2

CRISATEL HIGH RESOLUTION MULTISPECTRAL SYSTEM

Pascal COTTE and Marcel DUPOUY
LUMIERE TECHNOLOGY, Paris – France

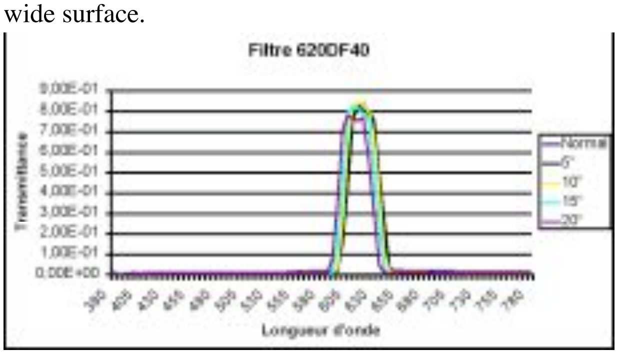
We have designed and built a high resolution multispectral image acquisition system for digitizing art paintings for the European CRISATEL Project http://www.crisatel.jussieu.fr,. This system consists of a multispectral digital camera and of special light projectors. The digital camera is a linear CCD array scanner and the lighting system provides a strip of light which scans the painting in synchronisation with the linear CCD array.

I – TECHNICAL PROBLEMS

The creation of a multispectral camera for the digitization of works of art must overcome several technical problems:

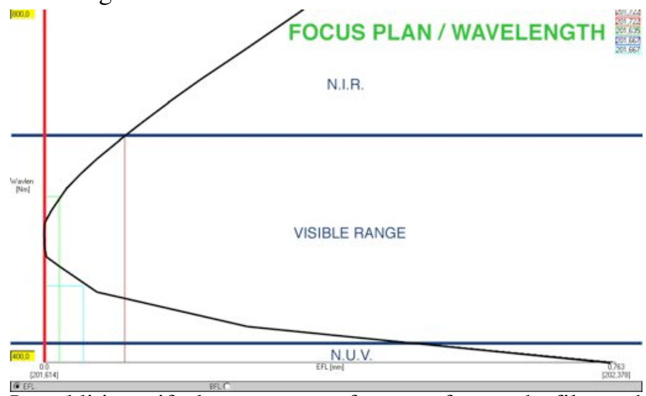
1) CCD ARRAY:
The camera needs to have an extremely high resolution in order to acquire sufficient detail in paintings that can be up to several metres in size. For example, for a painting of 3 x 2 m (10 x 7 feet) at 150 dpi 216,000,000 pixels (12,000 x 18,000) are necessary.
The accurate spectral analysis of paint pigments requires a sensitivity from wavelengths in the near ultra-violet to the near infra-red.
The sensor must, therefore, have both sufficient resolution and be sensitive across a wide spectral range.

2) THE MULTISPECTRAL FILTERS:
The filters need to have a uniform response across the whole surface. Interference filters, which have a very narrow angle of incidence are not normally appropriate for scans across a wide surface.



The characteristics of the filter change with respect to the angle of incidence.

3) THE OPTICAL SYSTEM:
No lens is capble of remaining in focus from UV to IR wavelengths.



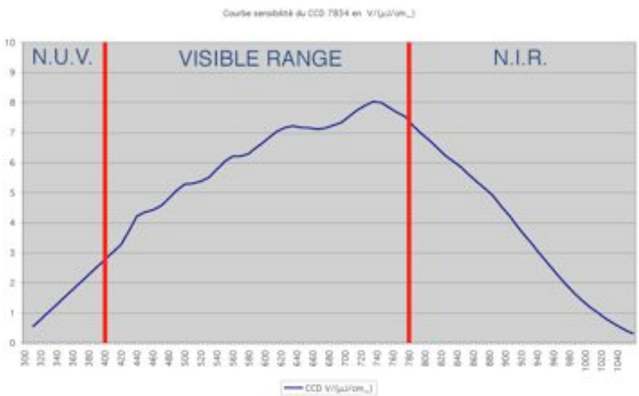
In addition, if the system refocuses for each filter, the images will no longer be superimposable, as they will no longer be at the same scale.

4) THE LIGHTING:
The light needs to possess the following characteristics :
- Be very bright and homogeneous
- Have at least 100,000 lux of power
- Should not expose the paintings to more than 50 lux per hour
- Have a smooth and flat spectrum suitable for multispectral analysis.

II - THE CRISATEL SOLUTION

1) 12,000 pixel CCD:
We use a linear CCD used in the aerospace and satellite industry: the SPOT 5:

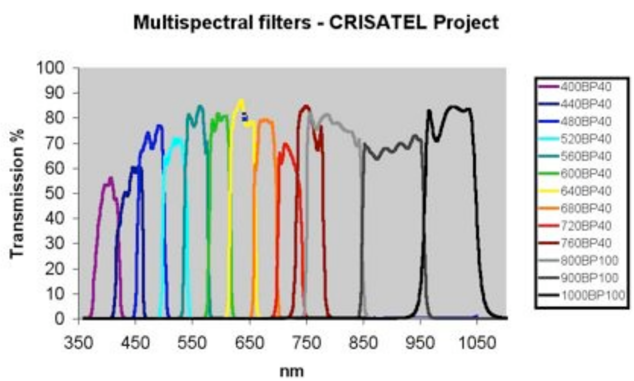
It has a resolution of 12,000 pixels of 6.5μm x 6.5μm. The sensor is mounted on a moving frame that allows the sensor to digitize 30,000 lines. The available capture surface is, therefore, 195mm x 78mm.



The sensor has a dynamic range of 10,000,
with 13 bit S/N.

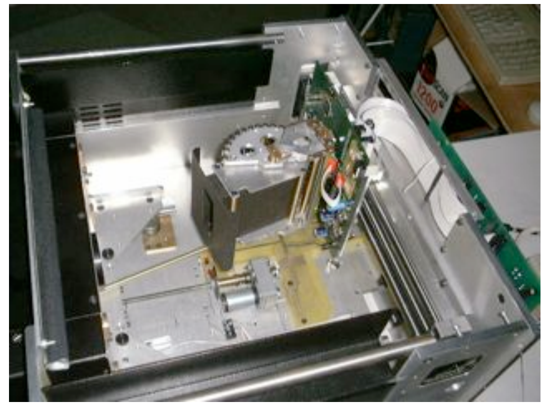
2) THE MULTISPECTRTAL FILTERS:

We have chosen interference filters specially made for the CRISATEL project. They cover the entire visible spectrum in narrow bands of 40nm and the near IR in three bands of 100nm.



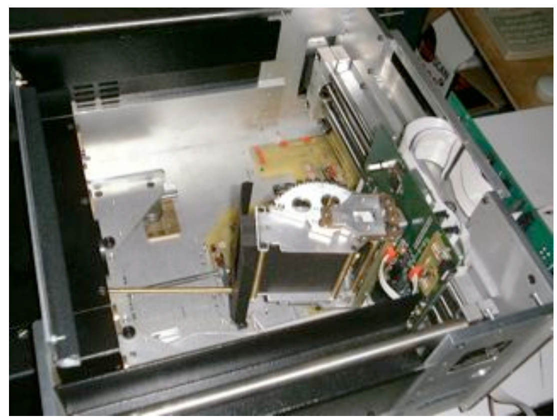
The filters are 10mm in front of the CCD. They are the height of the sensor length and are 7mm wide. A mechanical switch allows the filters to be changed.

Cask with 13 filters



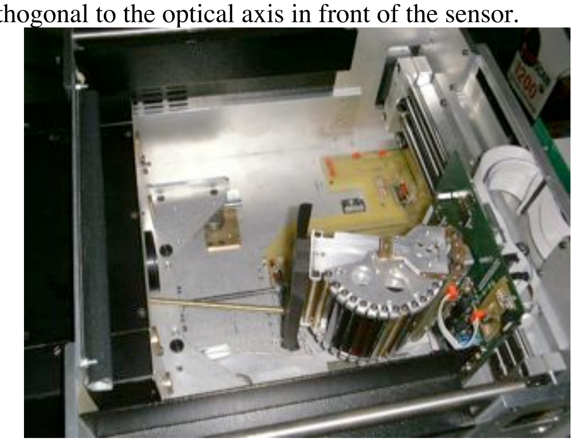
Interior view of the CRISATEL camera.
The CCD and the filters in the 'zero' position.

A mechanical system allows us to maintain the orthogonality of the optical axis in order to avoid problems relating to the change in response of the filters with respect to the angle of incidence.



The CCD and filters at the '30,000' position.
Cask filter on filter #1

During the duration of the scan, the filter remains orthogonal to the optical axis in front of the sensor.



Interior view of the CRISATEL camera.
Filter change operation.
Cask filter on filter #13

Finally a light guide (a black cover along the optical axis) prevents any problems arising from stray reflections.
Additional motorized filters :
It is also possible to combination of filters or to make a shutter.

3) THE OPTICAL SYSTEM:

View from the front of the CRISATEL camera.

A high precision stepper motor enables images for each filter to be focused. Precision 1/50 mm. Total course 100mm

*Camera position to **enlarge** the picture size..*

*Camera position to **reduce** the picture size.*

The correction for differences in scale is done via a mechanical system which adjusts the position of the camera with respect to the object being digitized. The whole apparatus is software controlled.
Precision 1/50 mm. Total course 100mm.

4) THE LIGHT :
Overview of JumboLux™ Lighting
JumboLux™ is a patented, self-calibrating, synchronised dynamic projection lighting system that has two banks of elliptic lights to illuminate the object in synchronization with the 12,000 pixel CCD array. During each sweep, a 100,000 lumen three-inch wide band of light is projected across the width of the object to provide momentary illumination. Since only a slice (e.g. not all) of the object is illuminated at a given time, the culmination of the sweeps exposes the object to minimal light .

Exposure to momentary light eliminate the possibility of fading or degrading light-sensitive watercolors and chemical-based paper drawings. In addition the JumboLux™ homogenous light eliminate refraction from shiny-surfaced objects and reflection from gilded (e.g. gold, silver and copper plate surfaces). Special filters limit surface temperature rise.The quality requirements of an archiving scanner are :
• SCAN SPEED.

• IMAGE QUALITY (SIGNAL / NOISE Ratio).
• DEPTH OF FIELD (Sharpness of old documents and parchments with ripples)
• PROTECTION OF THE ORIGINAL DOCUMENT
(Not excessive light, no UV B and no heat)

ALL THESE ADVANTAGES DEPEND ON THE QUANTITY OF LIGHT PROJECTED ONTO THE DOCUMENT DURING THE SCAN.

To summarise : the more projected light you have, the more you can close the aperture of the lens and achieve greater Depth of field, as well as achieving a faster scan. A larger CCD signal is important as it achieves a higher image quality. But this approach contradicts the Museum requirement to protect the archived object – by exposing documents with a minimum of light during the scanning process. The Museum's requirements motivated Lumière Technology to invent a new kind of motorized projector, making a line of light (instead of illuminating all the document with stationary lights), synchronized to the movement of the CCD.

Advantages of the projection lighting system :

A scanner's lighting system directly affects the dynamic range, sharpness, uniformity and capture speed of fine art, archival and historical documents. To achieve the objectives, Lumière Technology has developed and patented the JumboLux™ lighting system that momentarily 'sweeps' a narrow band of high intensity homogenous light across the entire width of the object in synchronisation with the CCD array. The higher light intensity and larger CCD signal form a unique combination that enables operators to generate higher quality images in less time, while protecting light-sensitive watercolors and chemical-based paper drawings from fading or degradation.

The JumboLux™ system's substantially increased light intensity enables operators to close down the lens aperture yet excite the CCD array in a fraction of the time required by conventional systems. This equates to a 5-10 times faster scan cycle. Operators can now scan an A0/E-size document at f-11 or greater to yield a 300 d.p.i. image in 18 seconds (single-sweep B/W and grayscale. Production time and labor costs are slashed to improve job turnaround and accelerate return on investment.

Since the JumboScan™ and JumboLux™ are portable, the scanner can be used in a variety of environments to scan reflective and transparent objects on copyboards, easels and walls.

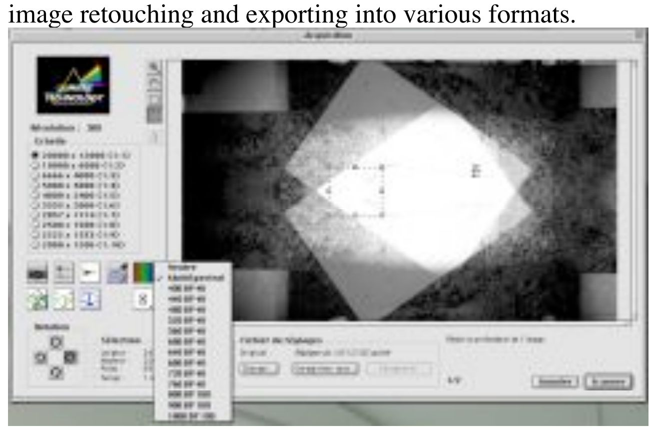
2. Increased Image Quality CCD density and lighting uniformity increase image quality in multiple ways :

• The 12,000 pixel CCD by 30,000 steps yields a 12-bit per channel file with a greater dynamic range and wider gamut – resulting in more details in the light and dark areas.
• The lens aperture can be closed up to f-16 to enable sharper images and greater depth of field without increasing scan times.
• Projected, rather than flooded light, only focuses on and illuminates the band that the CCD sees, to increase contrast and eliminate reflections on objects with two dimensional relief, gilt and varnish build up.

III – Technical Characteristics

1)The Software:

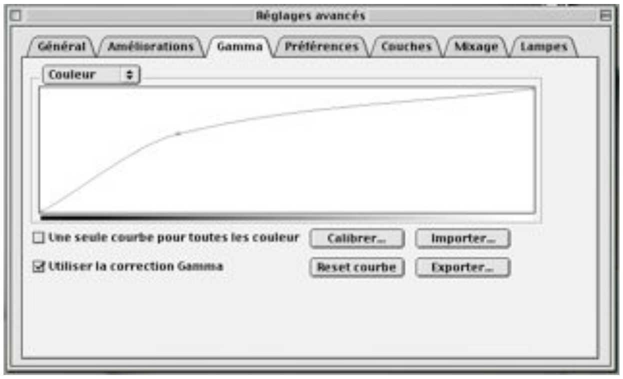
We have written a plug-in for the camera in order to allow image retouching and exporting into various formats.



There are numerous functions to control the camera and set parameters. The operator can choose to digitise multispectrally automatically or just scan using the chosen filters independently.

For each filter, you can choose:

- -gain (amplification of the signal)
- -exposure (from 0.7 ms to 100 ms)
- -the focus (absolute position)
- -the scale (absolute position)



Finally, for each filter it is also possible to edit a gamma curve (Look Up Table)

2) Scan Time and File Size:
The exposure time for each line is 10ms. For a painting of 1.5m (5 feet) digitized at 300 dpi requires 18,000 lines, making 3 minutes scan time per filter.
The file size is at most 12,000 x 30,000 x 13 = 4 .7 Gb at 8 bits per pixels uncompressed et 9.4 Gb at 16 bits per pixels uncompressed.

IV – APPLICATIONS

Spectral Reconstruction:
Using the data from the 13 filters and a system developed by the ENST Mr Francis Schmitt.

Academic Study:
Study of painting details. A scan with the CRISATEL camera is equivalent to 100 macro-photographic details. Studies of painting techniques.

Scientific:
Study of painting pigments, infra-red analysis, flourescence analysis (using UV)

Historical Research:
Virtual restoration of paintings. Analysis of paintings before expensive restorations.

Insurance:
Measurement of cracks, the study of the degradation of paintings. Fakes, painting recognition via spectral signatures and the geometry of details.

Commercial:
Visualisation of paintings with simulation of different lighting sources (eg sunlight, tungsten, halogen, candlelight etc.). Facsimile printing of perfect copies.
Restoration of original colours taking into account the light source being used.

Industrial:
Colorimetric controls (printing or manufacturing workflow etc.)
Spectral analysis of materials.
Analysis of rendered aspect.