What Makes Push-broom Hyperspectral Imaging Advantageous for Art Applications

Timo Hyvärinen
SPECIM, Spectral Imaging Ltd
Oulu Finland
www.specim.fi

ENHANCE YOUR PERCEPTION

Outline

What is hyperspectral imaging?

Hyperspectral imaging technigues

Push-broom hyperspectral imaging
- how it works in art applications?
- more information with broader spectral coverage

Summary

ENHANCE YOUR PERCEPTION

Hyperspectral Imaging - Spatial AND Spectral Resolution

The power and value of hyperspectral imaging is in its capability to
- Identify, Quantify (Measure) and Map
- chemical, physical and biological properties
- in each pixel of the target image.

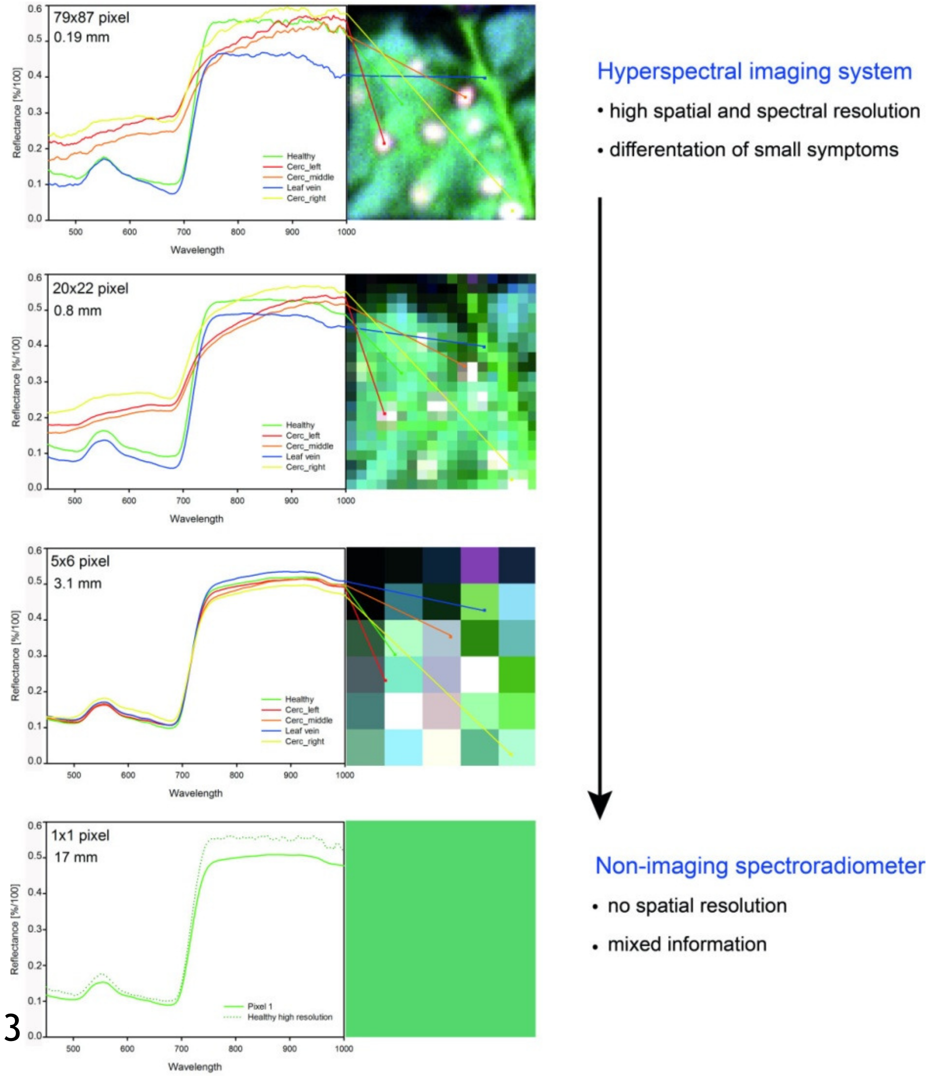


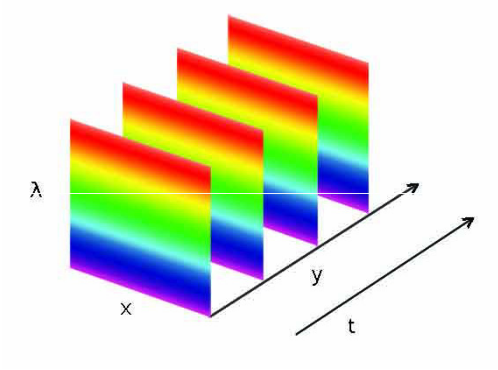
Figure:
Mahleun et al. Plant methods 2012, 8:3
http://www.plantmethods.com/content/8/1/3

Hyperspectral Imaging Techniques

1. Whisk-broom – point scanning
2. Push-broom – line scanning
3. Tuneable filters (LCTF, AOTF, F-BTF) – wavelength scanning
4. Imaging FTIR – time scanning
5. ’Full datacube snapshot’

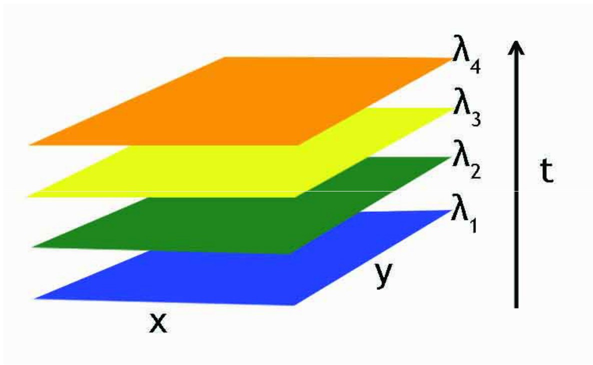
Two Main Approaches to Hyperspectral Imaging

Pushbroom



Full spectral data simultaneously, with spatial line scanning over time.
Imaging spectrograph + 2D array detector.

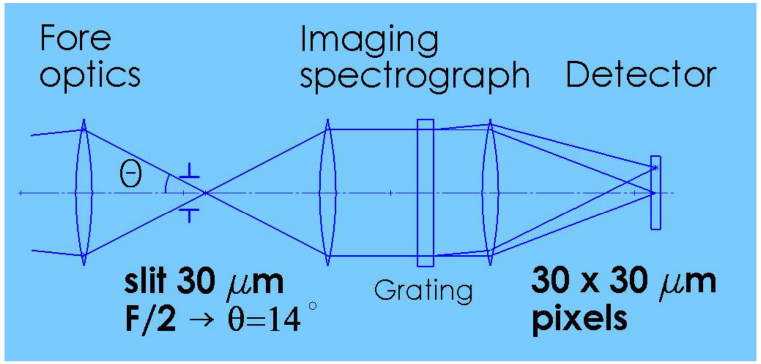
Tuneable spectral filter



2D image at a time, with wavelength scanning over time.
Tuneable filter + imaging optics + 2D detector array.

Light Throughput
(Area x Solid angle)

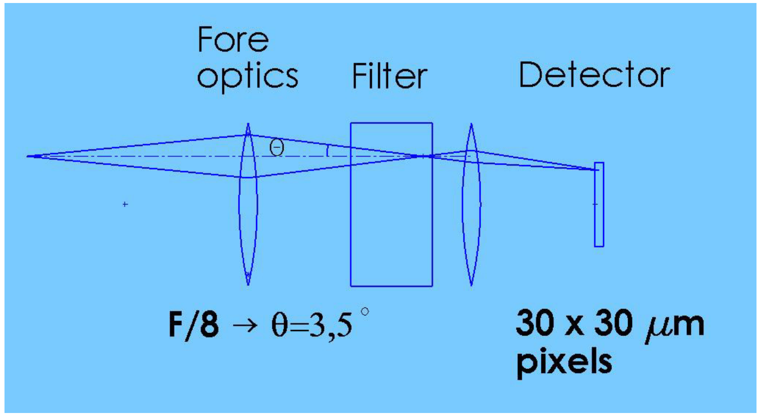
Pushbroom imaging spectrometer, 10 nm resol.



Solid angle, Ω = $2\pi(1-\cos\theta)$ = 0.19 sr

<u>$A\Omega$ = 17×10^{-11} $m^2 sr$</u>

Tuneable filter spectrometer (LCTF), 10 nm resol.



Ω = 0.012 sr

<u>$A\Omega$ = 2.4×10^{-11} $m^2 sr$</u>

Difference of 7x

Generic Push-broom Advantages

1. Acquires all spectral information exactly at the same time - insensitive to instrument/sample movement
2. No moving parts in the instrument – compact, reliable, stable, low maintenance.
3. **Collects light from sample to camera 5 to 20 times more efficiently than tuneable filter instruments.**
4. **Only a line across the sample needs to be illuminated**
   - 10 to 30 times more light ->Speed
   - Lower heat load on sensitive sample
5. Can be used as an imaging solution or as a multiple point fiberoptical spectrometer
6. **The only HSI technique which practically fits to all applications from lab to production, field and air**

Requires movement.

What Makes Push-broom Hyperspectral Imaging Advantageous for Art Applications ?

No need for uniform 2-dimensional illumination over large area.

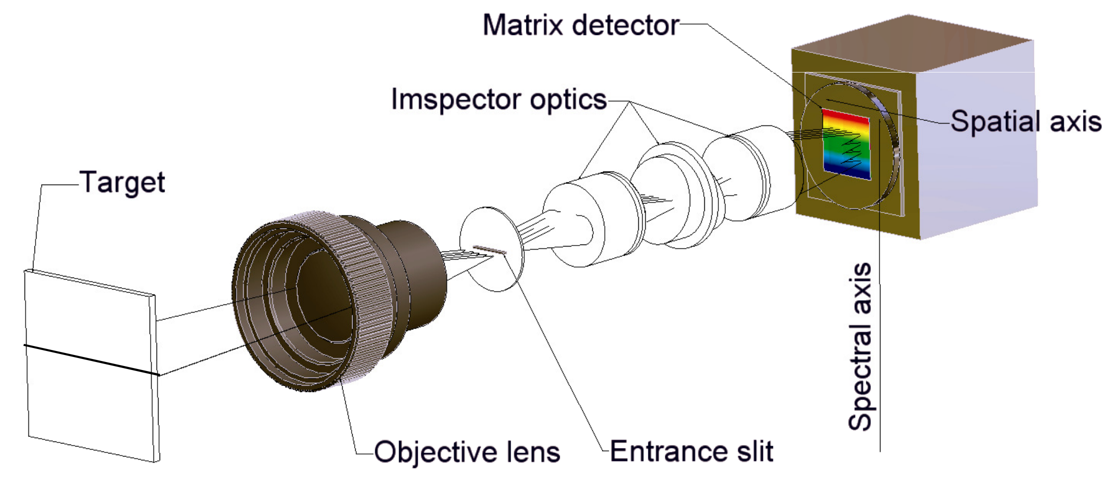
Low illuminance exposure.

Low heat load.

Maximal imaging speed.

Easily applied in different scales and orientations (wall, floor, desktop).

Push-broom Hyperspectral Camera

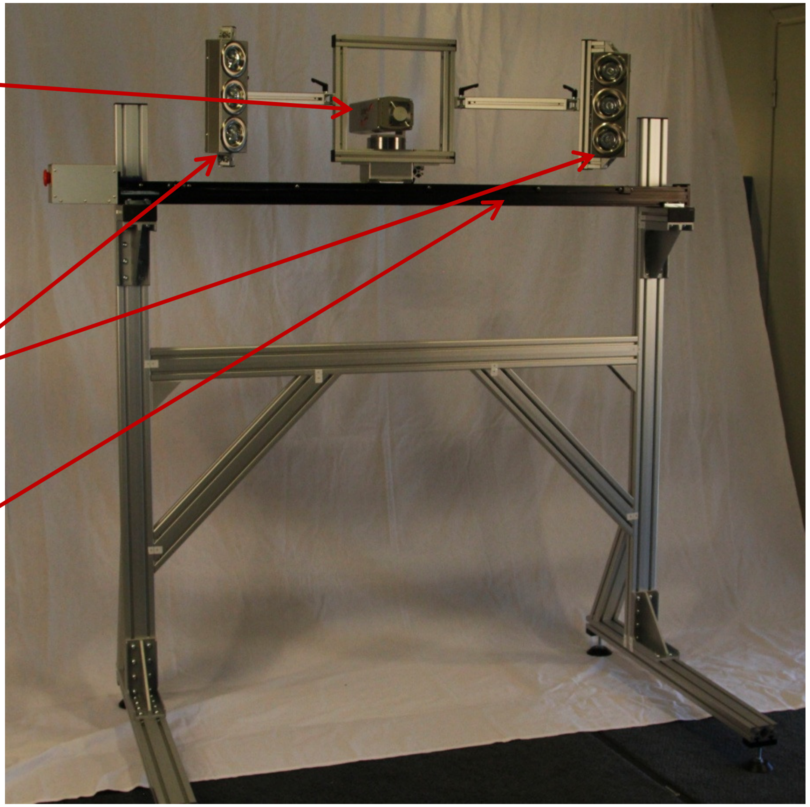


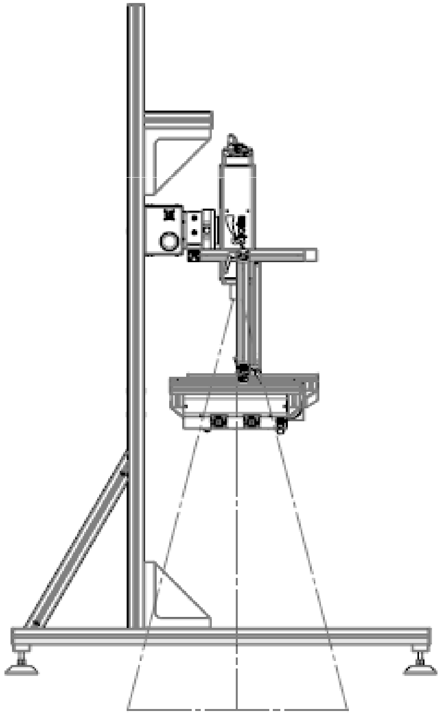
Push-broom Hyperspectral Scanner for Artwork

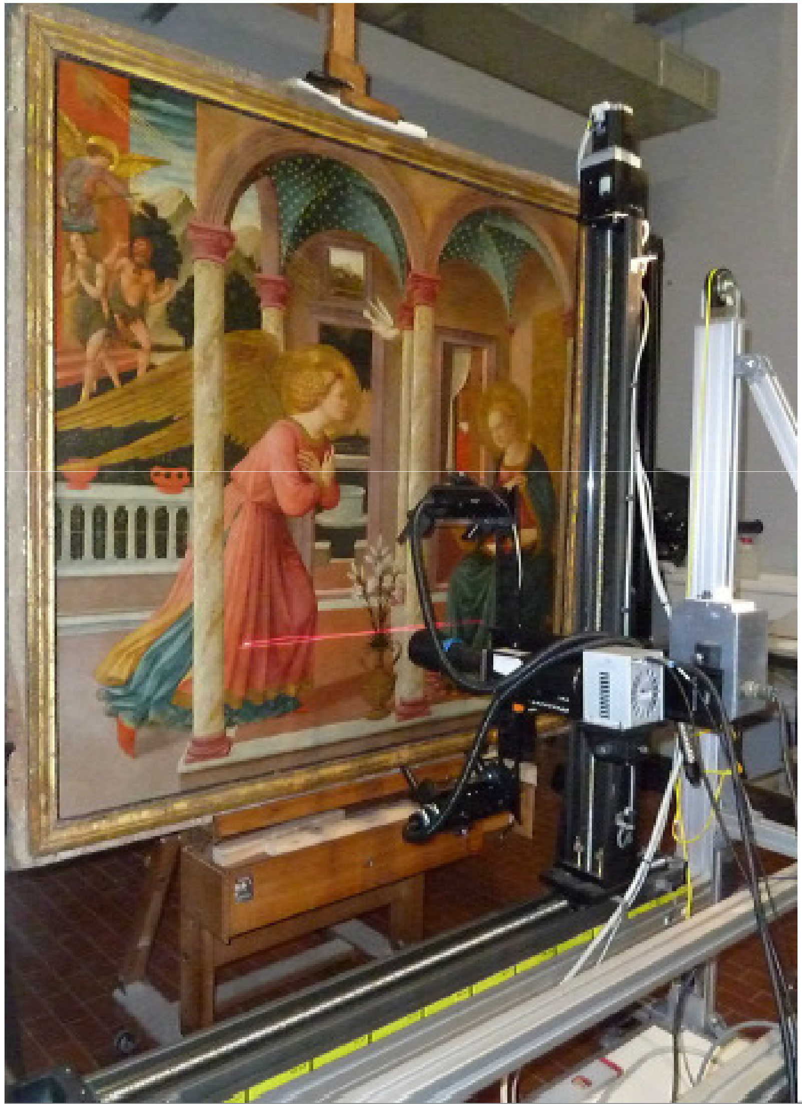
Push-broom hyperspectral camera with exchangeable front lens

Light source, moves with camera

Motor driven linear stage

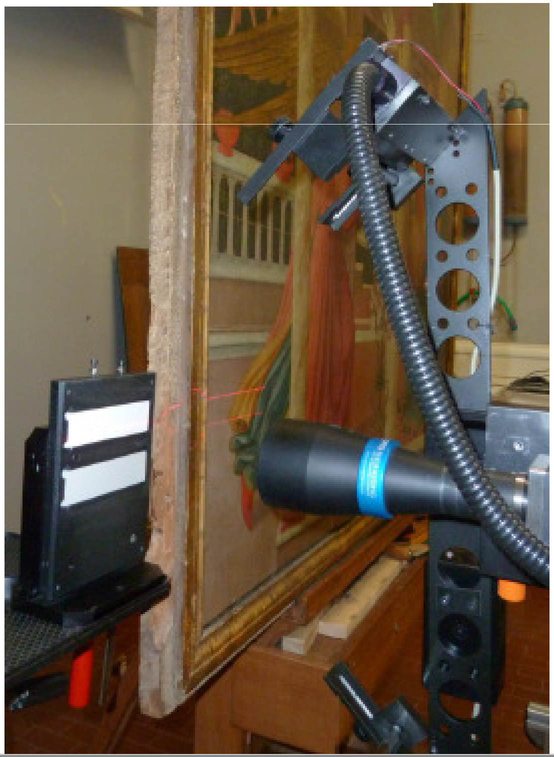






X/Y Scanning

Istituto di Fisica Applicata "N. Carrara" (IFAC-CNR)
Consiglio Nazionale delle Ricerche - Italy



Field of View

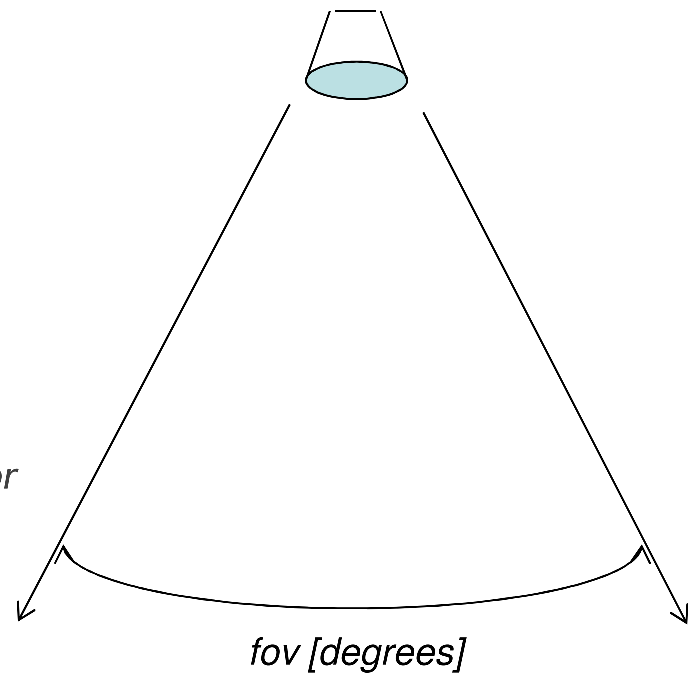
- Field-of-View (fov)
  - *fov for full detector*
  - *ifov for single pixel (take into account spatial binning if applied)*

$$fov = 2 * \arctan\left(\frac{ActiveSlitLength}{2 * LensFocalLength}\right)$$

ActiveSlitLength ≈ Spatial dimension of the detector

$$ifov = 2 * \arctan\left(\frac{PixelSize}{2 * LensFocalLength}\right)$$

$\approx$ *fov / #pixels*



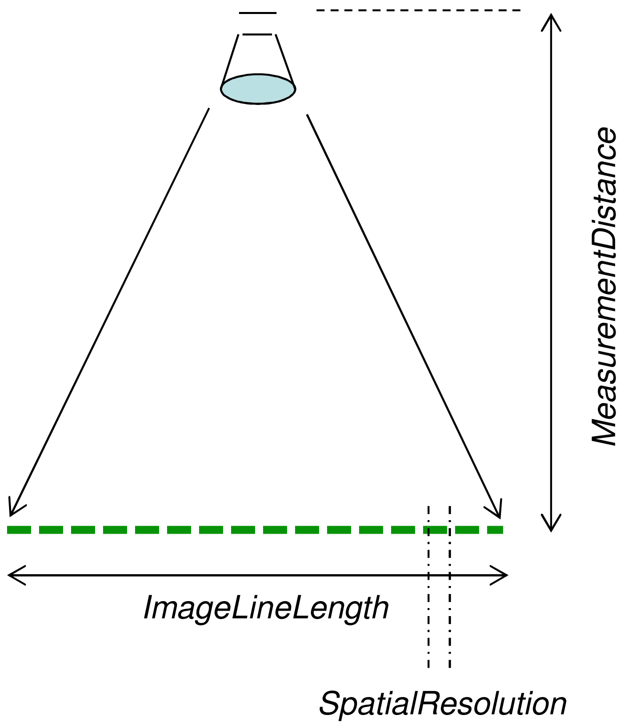
Spatial resolution on target

- Imaged line
  - *Line length*
  - *Line width*
  - *Spatial resolution along image line*

$$ImageLineLength = \frac{ActiveSlitLength * MeasurementDistance}{LensFocalLength}$$

$$ImageLineWidth = \frac{SlitWidth * MeasurementDistance}{LensFocalLength}$$

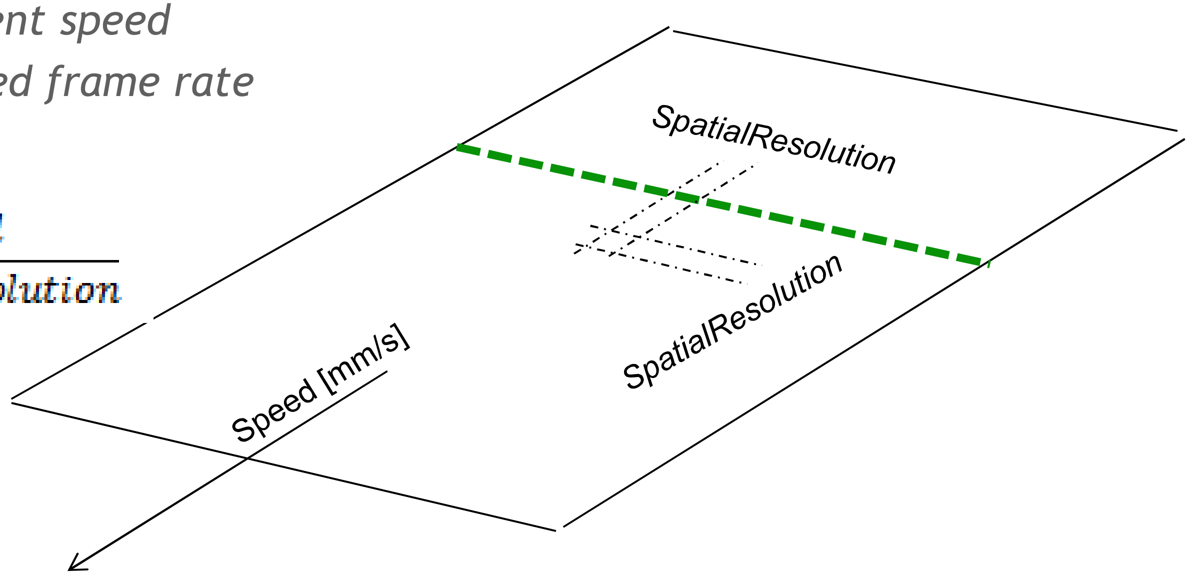
$$SpatialResolution = \frac{ImageLineLength}{AmountSpatialPixels}$$



Frame rate – Scan speed

- Spatial Resolution with movement
  - *Target is to achieve square pixel with sample movement, i.e. same resolution along movement as along the image line*
  - *Find out the movement speed*
  - *Calculate the required frame rate*
- Linear scan:

$$FrameRate = \frac{Speed}{SpatialResolution}$$



Integration time

- Signal level
  - *Maximum integration time achievable is frame period = 1/(frame rate). (Check from camera data, as all cameras may not reach this.)*
  - *Set integration time to achieve maximum signal level of ca 90% of the full scale from a white target.*
    (Note that signal varies with wavelength.)
  - *Signal may stay lower if there is not enough light. -> Reduce frame rate if possible in order to increase integration time.*

  - ***Always acquire Dark Image with the same integration time as the Sample (and White).***

Depth of Focus

- Depth of focus is the distance range for sharp image when the lens is focused to distance s:

From the "exact" equations for near and far limits of DOF, the DOF in front of the subject is

$$s - D_{\mathrm{N}} = \frac{Ncs(s-f)}{f^2 + Nc(s-f)},$$

and the DOF beyond the subject is

$$D_{\mathrm{F}} - s = \frac{Ncs(s-f)}{f^2 - Nc(s-f)}.$$

SPECIM Camera and Light Source Options

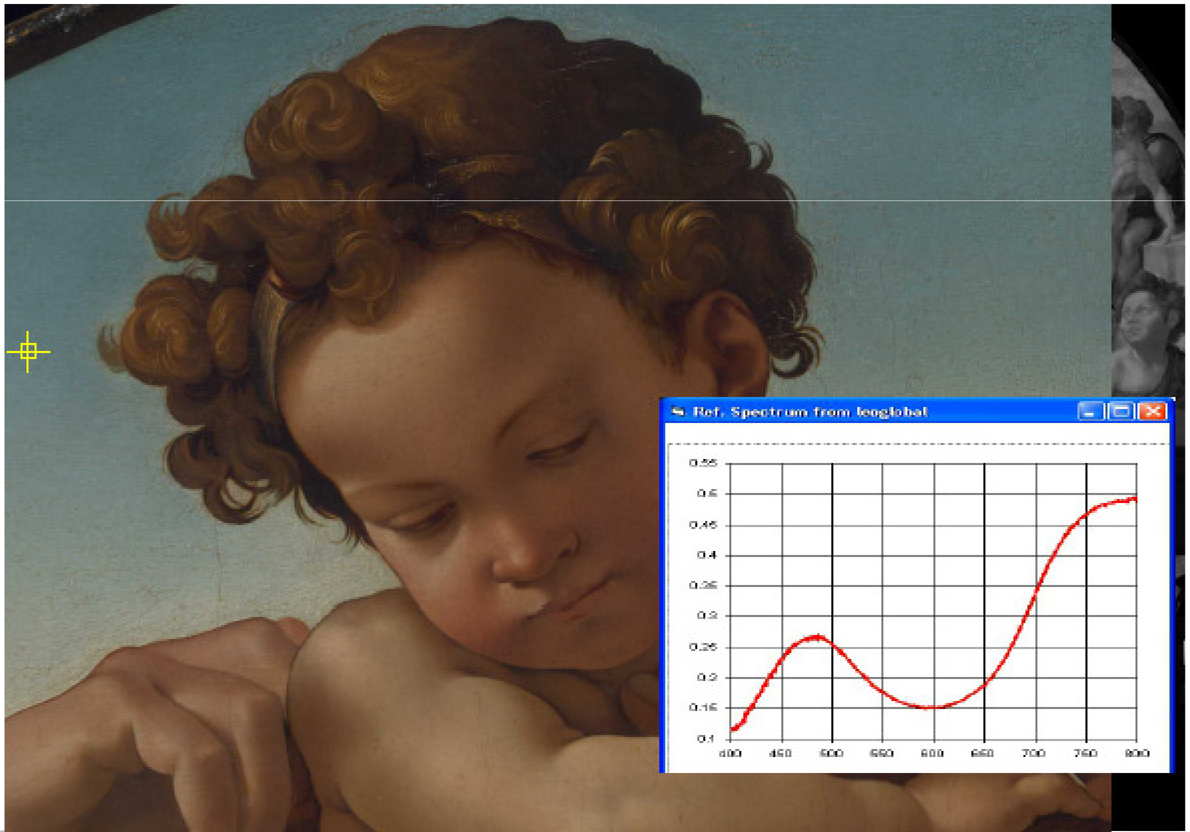
Camera options	Spectral sampling	Spatial sampling	Image rate
VNIR 400-1000 nm	1-8 nm	1000-2000 pix, 15 um ->	Up to 150 Hz
NIR 900-1700 nm	3.5 nm	320/640 pix, 30 um ->	Up to 350 Hz
SWIR 1000-2500 nm	5.5 nm	320 pix, 30 um ->	Up to 100 Hz
VNIR+SWIR 400-2500 nm in a single instrument coming			
MWIR 2600-5000 nm	30 nm	320/640 pix	Up 350 Hz
LWIR 8000-12000 nm	400 nm	384 pix	60 Hz

Light source options
Halogen based fiber optical line light (400-1700 nm) - Highly focused light line
Linear halogen array (400-2500 nm) - Less focused - Higher illumination and heat load
UV light for fluorescence

More Information with Broader Spectral Coverage

VNIR 400-1000 nm

Documentation of valuable artwork.
Pigment identification.
Color reproduction.

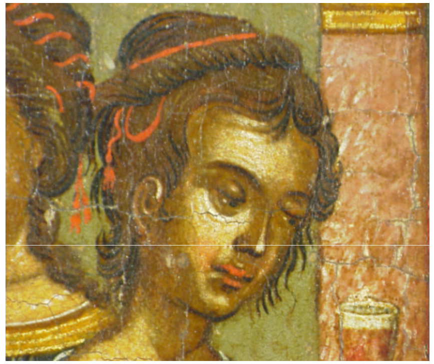


Istituto di Fisica Applicata "N. Carrara" (IFAC-CNR)
Consiglio Nazionale delle Ricerche - Italy

More Information with Broader Spectral Coverage

VNIR 400-1000 nm
Documentation of valuable artwork.
Pigment identification.
Color reproduction.

NIR/SWIR 900-1700 nm/1000-2500 nm
Inspection of inner layers (under-drawings and retouches).
Improved chemical material identification/ discrimination.



Institute of Spanish Cultural Heritage

Color – SWIR – X ray

RGB

SWIR at 1600 nm

X-ray

”SWIR hyperspectral imaging provides more detailed inner layer and under-drawing information than X-ray”

Agata Warszewska
Museum of Wroclaw, Poland

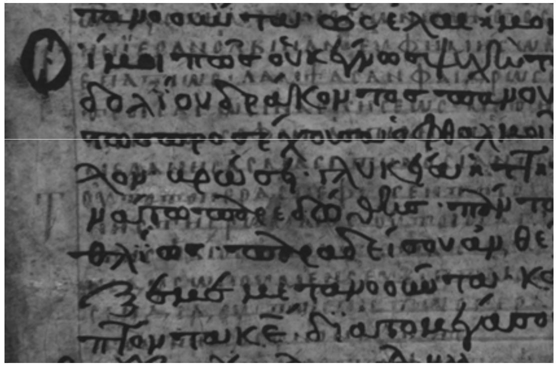
Composition by Henryk Statewski, 1957, oil

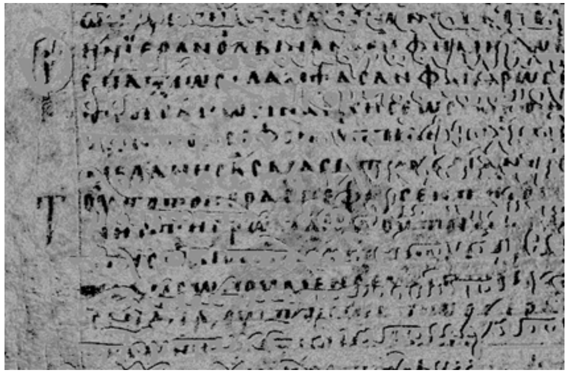
More Information with Broader Spectral Coverage

VNIR 400-1000 nm
Documentation of valuable artwork.
Pigment identification.
Color reproduction.

NIR/SWIR 900-1700 nm/1000-2500 nm
Inspection of inner layers (under-drawings and retouches).
Improved chemical material identification/ discrimination.
Manuscript investigations.

Institute of Spanish Cultural Heritage





More Information with Broader Spectral Coverage

VNIR 400-1000 nm
Documentation of valuable artwork.
Pigment identification.
Color reproduction.

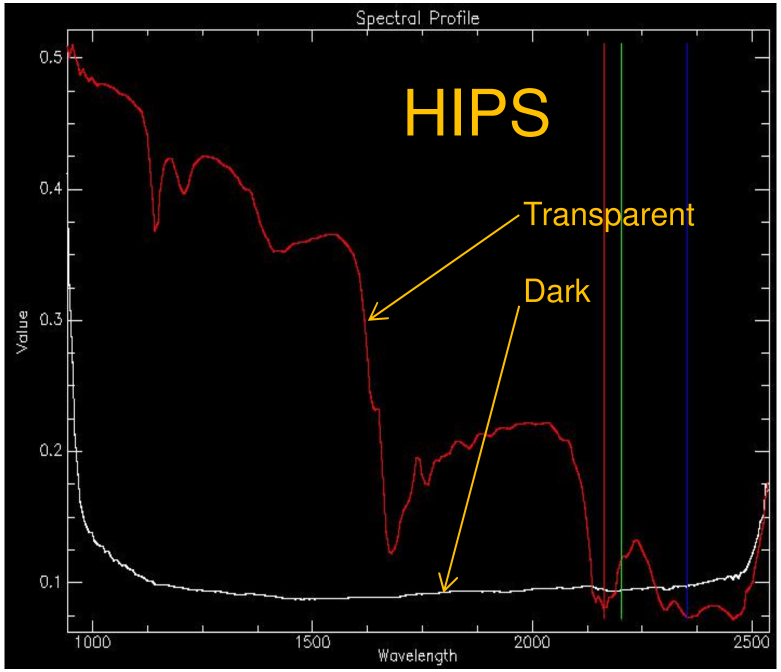
NIR/SWIR 900-1700 nm/1000-2500 nm
Inspection of inner layers (under-drawings and retouches).
Improved chemical material identification/ discrimination.
Manuscript investigations.

MWIR 2.6-5 um
Could additional information be achieved in the infrared?
Cameras are available.
Light source needs to be optimized for reduced heat load.

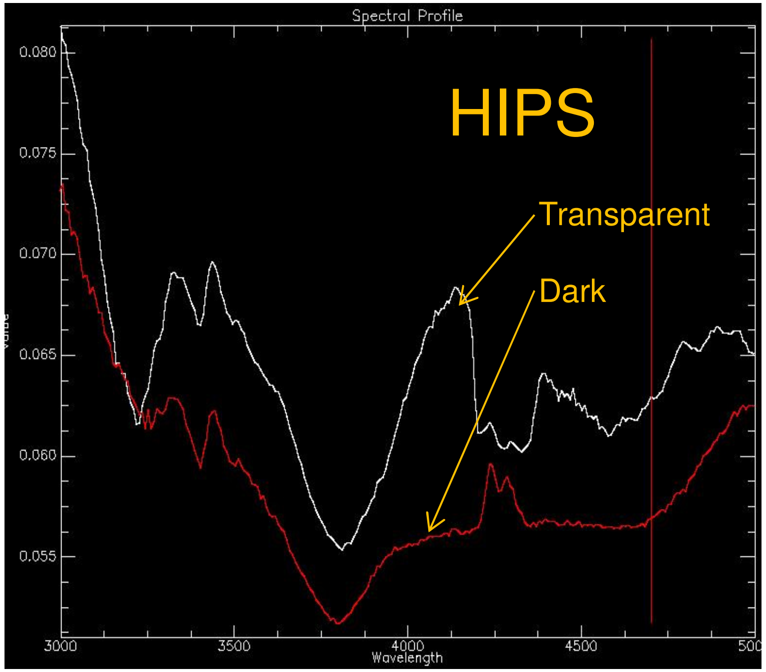
MWIR Hyperspectral Imaging Penetrates into Industrial Applications

Sorting of black materials in reflection mode

SWIR



MWIR



Summary

Hyperspectral imaging is becoming recognized and versatile tool in artwork documentation, pigment identification and discrimination, color reproduction and in analysis of under-layer drawings.

Push-broom imaging simplifies illumination requirements, minimizes illumination exposure and heat load, and maximizes imaging speed.

Thank you!

Specim

ENHANCE YOUR PERCEPTION