CLYDE HSI

Art Scanners

Intelligent Hyper-Spectral Imaging Systems

Seeing is Believing : Hyper-Spectral Imaging across the Rainbow for Art and Art Conservation

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The Power of Optical Spectroscopy

Optical spectroscopy is the science that is concerned with the interaction of optical electromagnetic radiation with matter. Optical spectroscopy is a non-contact and non-invasive technique that is also non-destructive. It requires little sample preparation thus saving on measurement time and materials cost. It is very well suited to a large range of applications for scientific measurements as well as being easily transferred to on-line process monitoring applications.

The optical spectrum provides a unique "finger-print" of the material under investigation and when used with appropriate calibration and validation models it can be a very powerful diagnostic tool.

The mode of measurement can be by: reflectance, absorption, transmission, emission, luminescence, or by a scattering method such as Raman, Debye or Mie Scattering.

Single point optical spectroscopy measurements are often undertaken by measuring the average signal over a single specific area of a target sample. Therefore, it has difficulty to assess target properties where there is a large variation in spatial features because the measured spectrum is averaged over the measurement area, thus only average, or bulk material effects can be analysed. Inhomogeneous distributions within a target sample, for example in paintings or documents require many measurements to be made which is very time consuming and open to errors.

Photography and the Spectrometer

During the early part of the 19th century when Niepce, Fox-Talbot and others were experimenting with methods to produce pictures with the aid of sunlight, a new and parallel investigation was underway in the investigation of the properties of light by using a prism, and much later, a diffraction grating, to separate light into their separate colours.

Thus both photography and optical spectroscopy have largely developed in parallel and have also mutually benefited from each other. Indeed, it is true that photography has been a key recording method in terms of spectroscopic measurements.

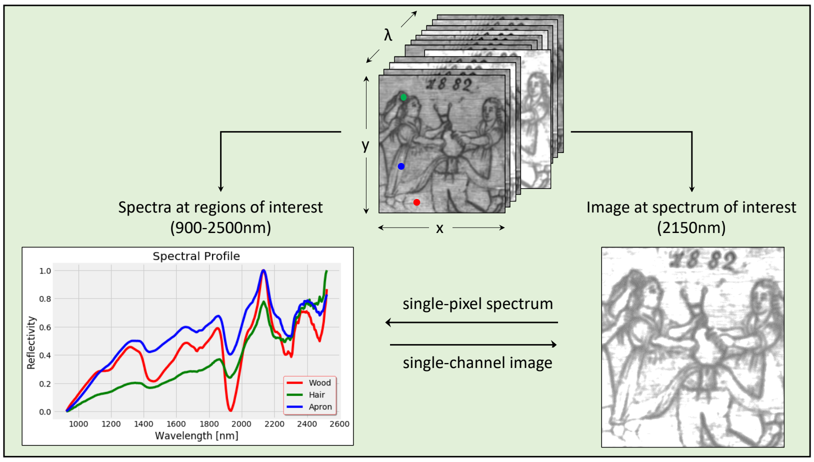
The early experiments of Sir Isaac Newton in the late 17th century used a glass prism and a round entrance aperture and then a rather wide slit type aperture. These experiments demonstrated a broad visible spectrum and artists often spoke of this demonstrating the primary colours. Almost at the same time, James Gregory, the Scottish mathematician and astronomer, in 1673 demonstrated the splitting of colours from sunlight using a bird feather – this was essentially the first demonstration of the principle of the diffraction grating. Almost one hundred and twenty five years later William Hyde Wollaston in 1802 substituted a narrow slit for the large aperture used by Newton and observed "a purer set of colours and better graduation of tint". At the same time he observed fine black lines. Within 12 years, Joseph von Fraunhofer had developed the technique further and as a glass maker had developed Wollaston's work into an operating spectroscope using which he was able to clarify 574 black or absorption lines in the solar spectrum. These lines were later shown to be atomic absorption lines by Kirchoff and Bunsen in 1859. David Rittenhouse manufactured a 'man-made' diffraction grating in 1785 using threads separated using a fine pitch screw. Fraunhofer used the same technique in 1821 using fine wire instead of threads. Thus practical and affordable diffraction gratings had been formed to act as spectroscopic elements.

In parallel, developments in the science of photography had greatly advanced and by the end of the 19th century acetate coated photographic film was widely available along with the processing possibilities.

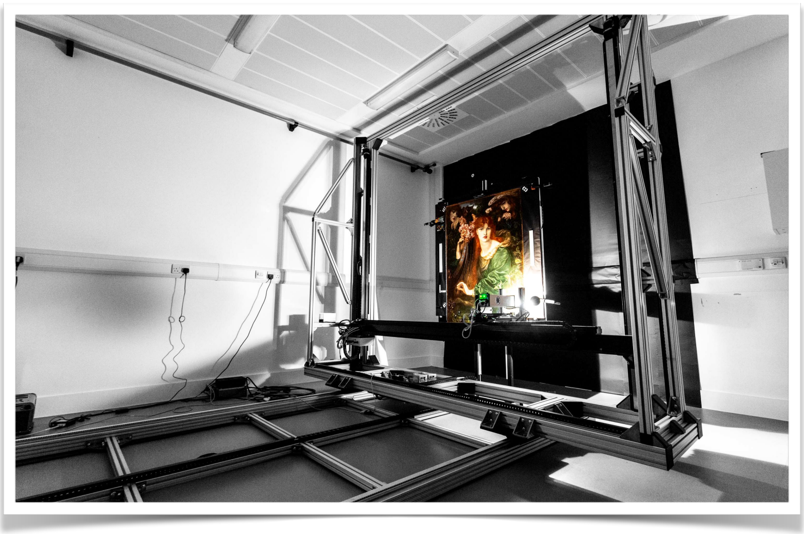
Combining these two instruments: the spectroscope and the photographic camera, we would now recognise this instrument as the modern spectrometer with later developments making spectral cameras.

Hyper-Spectral Imaging

Hyper-spectral imaging is the combination of 'spectroscopy' and 'imaging', which can provide the spatial distributions of materials and therefore the heterogeneity of a material can be assessed. This is possible because the measurement records each pixel position in the object plane and measures a full optical spectrum at each pixel. Thus, hyper-spectral imaging allows the identification, distribution, and concentration of components within a target or product to be viewed based upon their spectral signatures.



Hyper-spectral imaging allows flexible selection of regions of interest for further analysis without the need for remeasuring the sample. This allows certain sample features to be quickly classified and their spectral signatures to be stored for future reference in a spectral library or database. Hyper-spectral imaging has excellent detection limits.



Condition Assessment and Monitoring of Historical Documents, Archaeology and Art Conservation

Hyper-spectral imaging has over the last three decades developed into a smart analytical tool for a range of applications including: remote sensing, food and agricultural assessments, forensics, etc. In the last twenty years or so, hyper-spectral imaging has been adopted by the cultural heritage community for inspection of historic documents, works of arts, sculptures and reliefs as well as in archaeology.

The basic hyper-spectral techniques create a spatial map of spectral features that enables identification of material components and their spatial distribution. This is done optically and without contact to any material of the artefact. As such hyper-spectral imaging has become one of the key analytical tools for evaluating historical documents and art works. The reason is that the spectral features are a "fingerprint" of the material and hence spectral imaging has developed into a highly quantitative and sensitive approach for detecting, measuring and visualising changes in the optical properties of historical works. It is here that optical spectroscopy and especially hyper-spectral imaging has become very successful as it is non-destructive, non-contact, and can simultaneously determine several parameters in real-time.

Size, shape, colour, surface texture can all be easily measured using conventional machine vision approaches. The prediction of other parameters, such as the chemical composition of an artwork, its degradation or change over time and especially at levels not possible to detect with the human eye can all be derived from hyper-spectral imaging results.

Hyper-spectral data sets can often have multi-collinearity, that is a phenomenon in which one predictor variable in a multiple regression model can be linearly predicted from the others with a substantial degree of accuracy. This is an advantage; however, this also means that small variances in parameter values or models can influence greatly the result. This disadvantage can often be overcome by using multi-variate analysis and appropriate variable selections.

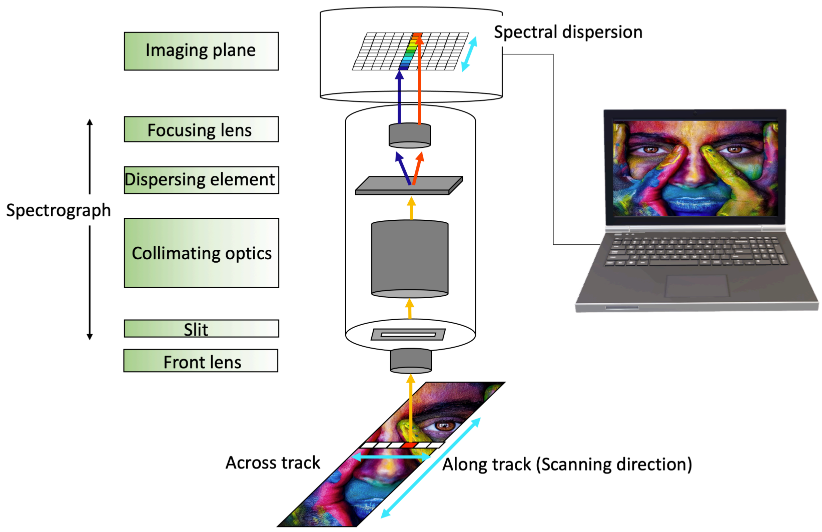
Push-Broom Hyper-Spectral Imaging

Push-broom hyper-spectral cameras are essentially a special type of line scan cameras. In other words, they measure one line at a time and at each pixel point along that line they measure an optical spectrum. This is an optically efficient process and permits both high-spatial and spectral resolutions to be obtained. A 2-dimensional image is constructed my moving the measurement line across an object to be studied. Very large area can be scanned at high resolution by performing a multi-strip measurement with an overlap between strips. They can then be stitched together by appropriate mosaic algorithms that join and blend features.

Using spectral imaging systems, one can achieve very significant additional information about sample behaviour and dynamics and such imaging systems can present close to photographic imaging quality.

Due to the fact that each individual image pixel has a complete optical spectrum associated with it, the resulting image contains a wealth of data that can be processed to provide spatial, spectral, and concentration information.

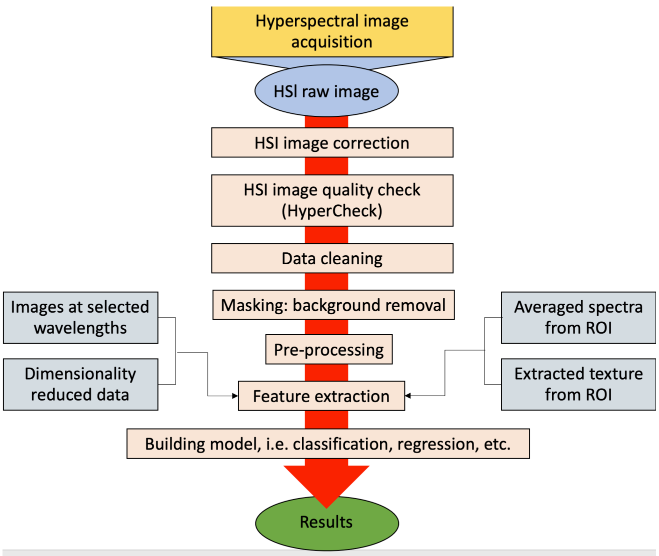
The complete optical system for a hyper-spectral push-broom camera consists of a suitable objective lens matched to the spatial and spectral requirements of the application, the imaging spectrograph proper and a two-dimensional detector to simultaneously collect the spectral vs. spatial information.



Typical push-broom spectral camera arrangement

Spectral and Image Processing

The key task for spectral imaging is to identify the materials at each pixel using the recorded optical spectrum, then to determine distribution of materials and if suitable calibrated their concentrations. spectrSENS software controls the whole process from data acquisition to spectral and image processing. All data sets are available and can be input to other programs commonly used for hyper spectral images.

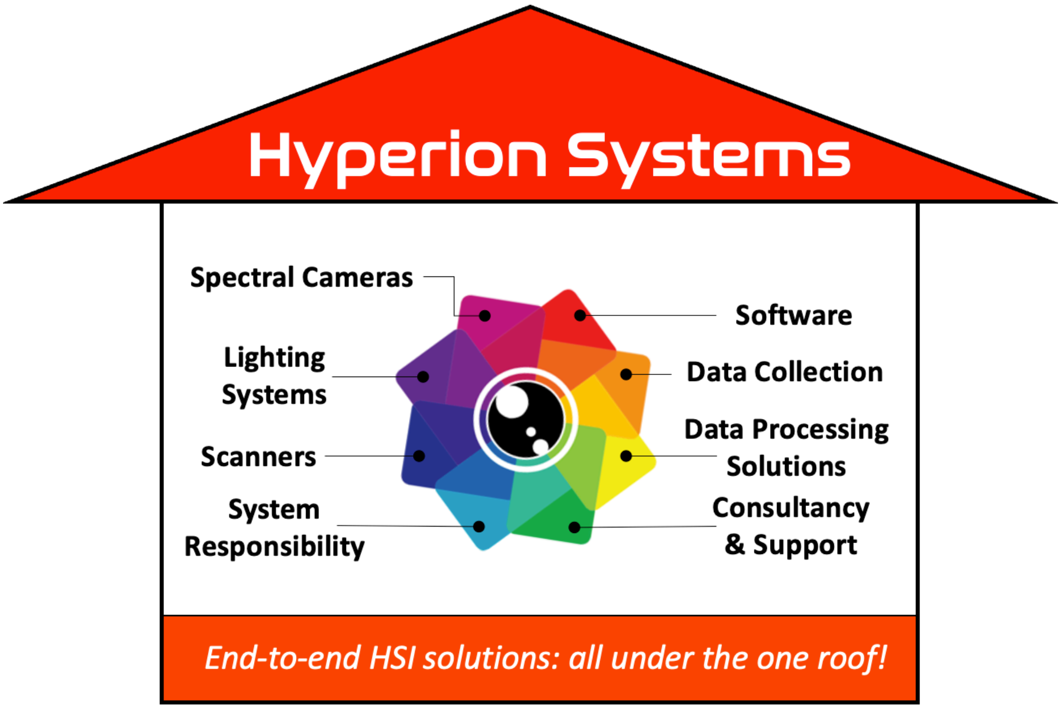


Comprehensive data acquisition and analysis functions are standard within spectraSENS software. These allow spectral analysis to be performed and they can be combined to form analysis workflows that can be saved as an acquisition / analysis method for re-use later.

The HyperCheck function performs an automatic quality check of the collected hyper spectral data set. It therefore allows the system operator to validate the measurement quality and to decide if any addition checks or adjustment of the system are needed. Such a check includes categorises the image into categories for action: ***The Good, The Bad,*** *and* ***The Ugly***

For example : Number of drop-out frames; SNR; Under-/Over-exposed pixels, bad pixels; and so on.

Clyde HSI has developed comprehensive solutions for hyper-spectral imaging across the rainbow. These systems, are based on our Hyperion hardware solutions and spectraSENS software. Comprehensive, complete, and fully supported by ClydeHSI



Hyperion Art Scanners

The Hyperion HSI Art Scanners are designed as complete end-to-end solutions that make robust, reliable, accurate, and repeatable hyper-spectral measurements across documents and large art structures such as paintings and 3-dimensional objects.

Each Hyperion scanner comprises of a complete turn-key hyper-spectral solution that includes spectral camera, scanning stage, lighting system, focus targets, reflectance standards, and software for data acquisition, viewing and analysis.

Ease-of-use and speed-of-acquisition are key features of these systems.

Six scanning configurations are available with five spectral camera options. These scanners can be quickly set-up on either a tripod mount, a standard table, or as a complete large area scanner that can then acquire high-resolution spectral images in seconds.

All scanners can hold up to two spectral cameras thus offering both VNIR and NIR, or SWIR, spectral ranges at the same time. Each spectral camera unit comes with an interchangeable objective lens that allows optimisation of the stand-off distance and magnification to achieve high spatial resolution needs, including macro work on target.

Once the objective lens is focussed to target, the whole spectral camera can be adjusted in stand-off distance to accommodate samples of different thickness without the need to refocus. By using a shorter stand-off distance, the cross-track length can be reduced, and the spatial resolution increased.

Each instrument is delivered calibrated and with a certificate of conformance. The spectral calibration is made, and the image performance tested and demonstrated using calibration targets.

Key Features	Advantages of the Hyperion System
High sensitivity, wide spectral range hyper-spectral camera options: • VNIR: 400 to 1000nm • NIR: 900 to 1700nm • SWIR: 900 to 2500nm	Fast acquisition with minimum required illumination exposure to the art work Superb spectral resolution and signal-to-noise performance Can measure both colour and chemical information about the target object Can provide cost effective deployment of instrument Modular approach: buy what you need now and add later as required
Matched optics to ensure equivalent pixel size on target	Enhances the ability to fuse data sets with minimum geometric corrections
Photography and reference camera options	Can take conventional photography image to use to select features of interest to guide the scanner or to fuse data with. Range of cameras supported up to to 400MPix
Low optical power required	Importantly, the high system sensitivity means that the optical intensity required to make the reflectance measurements can be low even for high resolution scans and this means minimum optical exposure to the art work or document under investigation.
High precision robust scanner system	High precision large area scanners with resolution capability to easily accommodate macro scanning over distances in excess of 2m x 2m.
Automatic stand-off distance measurement	No need to guess the distance or measure with conventional tape measure or stick. Automatically measured and provide spatial map of the subject profile during measurement.
Reference marks and white and black reflectivity tiles	Fiducial marks allow direct geometric assessment of the imaging area. White and black reflectivity tiles can be automatically integrated to the workflow for reflectivity calculations and exposure checking.
Complete Acquisition and Analysis software	Advanced acquisition and analysis software are provided with the instrument. ClydeHSI is responsible for the operation and support of the whole system.

We offer six main system configurations for different application needs. These systems are all interchangeable as the spectral cameras from one can be used with another without any adjustment due to the modular systems approach taken.

System Type	Description
Portable Rotary	Allow high speed acquisition of HSI data sets for large objects and can simply deployed on a tripod
Portable Linear	Linear scanners for 1-D applications. Can be supported on two tripods or self standing on a single tripod.
Desktop	A3 and A4 precision linear or 1m^2 2-D scanner systems for document scanning and includes automatic position of focus marks, and white tile corrections. Capable of macro scanning at resolution to 15µm.
2-D large Area	Large area scanner for objects up to 1m x 1m or 2.5m x 2.5m with macro capability to 25µm across the full target area. Automatic stand-off distance measurement, shape tracking facility and stand-off distance adjustment that maintains the system geometry to artwork. Hi-Res photography option.
Microscope	Ultra-high spatial resolution hyper spectral images over areas up to 300mm x 300mm in reflectance, transmission, luminescence, and polarisation measurement options.
Robotic Arm	Complex objects can be scanned in 2-D or 3-D using the robotic arm scanner. High spatial position and repeatability. Can be used with up to two mounted VNIR and NIR cameras to provide 3-D hyper-spectral images

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Application Guide

Different applications or art work targets require different scanning considerations

Application / Scanner	Rotary	Linear	Desktop	Microscope	2-D Large Area	Robot Arm
Archeology	●	●		●		●
Architecture	●	●				●
Artworks	●	●	●	●	●	●
Books		●	●	●		
Ceramics		●	●	●	●	●
Conservation	●	●	●	●	●	●
Documents		●	●	●		
Embroidary		●	●	●	●	
Film			●	●		
Furniture	●	●			●	●
Icons	●	●	●	●	●	●
Illuminated Manuscripts		●	●	●	●	
Maps	●	●	●	●	●	
Mosaics	●	●	●	●	●	
Museum Collections	●	●	●	●	●	●
Paintings - Very Large Area	●				●	●
Paintings - Large Area	●	●			●	●
Paintings - Small Area	●	●	●	●	●	
Paintings - Miniatures		●	●	●		
Printing			●	●		
Restoration	●	●	●	●	●	●
Sculptures	●	●			●	●
Tapestries	●	●			●	
Textiles	●	●	●	●		
Wall Paintings	●	●				

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Rotary Scanner

The rotary scanner solution is ideal for very large scenes ,where large areas are to be scanned quickly, for use with telephoto objectives, or with UV hyper-spectral cameras where other scanner types may not be appropriate. Rotary scanners include a zero-datum sensor and can be used either in horizontal or vertical scanning modes. Scanners are available for all hyper-spectral camera configurations including single camera and dual VNIR and SWIR systems.

It is compact, quick and easy to set-up and to make measurements in “difficult” locations.

FOV and IFOV are automatically calculated for the objective lens in use and this enables auto-square-pixel facility to set scan rotation speeds appropriately and synchronise with the spectral camera frame rates.

Parameter	Value	Units	Comment
Angle of Rotation	360	Deg	Unlimited total rotation, scan between angles, forward and reverse operation
Angular Resolution	≤ 0.005	Deg	Angular resolution and optical stand-off sets the on target spatial resolution
Angular Scan Speed	≤ 25	Deg / s	Please consult ClydeHSI for higher scan speeds
Operation	Vertical or Horizontal	-	Adapter
Mounting	⅜ or ¼”	-	Fits all tripod systems using standard camera mounts
Interface	USB	-	USB compliant, Adapters available for RS 232,and RS 422/485
Power	24	V DC	Reverse polarity protected, PSU supplied, rechargeable battery packs available.

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Linear Scanner

Professional grade 1.0m long precision camera slider that can be suspended between two tripods or on single tripod with bracing arms. Stepper motor driven translation with opto-sensor zero-position datum, anti-vibration shock absorbers, precise index marks, and over travel ends-switches for safety. Payload capability 30kg

Linear translation stages are ideal for many small to medium sized objects and where the application requires scanning in only one direction. Fully integrated and controlled by spectraSENS software with high precision zero datum optical sensors, these stages are a cost effective first step into area scanning. Such stages can be used with any single or dual hyper-spectral camera arrangement in a horizontal or vertical scanning direction. They can be used between two tripods for mobile applications: looking sideways or downward depending upon the application needs.

Combined with a lighting system , linear scanners make a comprehensive, portable, and effective solution for many applications.

Parameter	Value	Units	Comment
Length of Translation	300, 500, 1000, 1500	mm	Other translation lengths are available, please consult ClydeHSI.
Step resolution	25	µm	Full step, micro stepping is also possible in factors of 2, 4, 8, and 16 providing step resolutions as small as 1.6µm/ step
Sensors	3	-	High precision
Max. Linear Speed	50	mm / s	Higher speed version as available as custom designs, pleased consult ClydeHSI.

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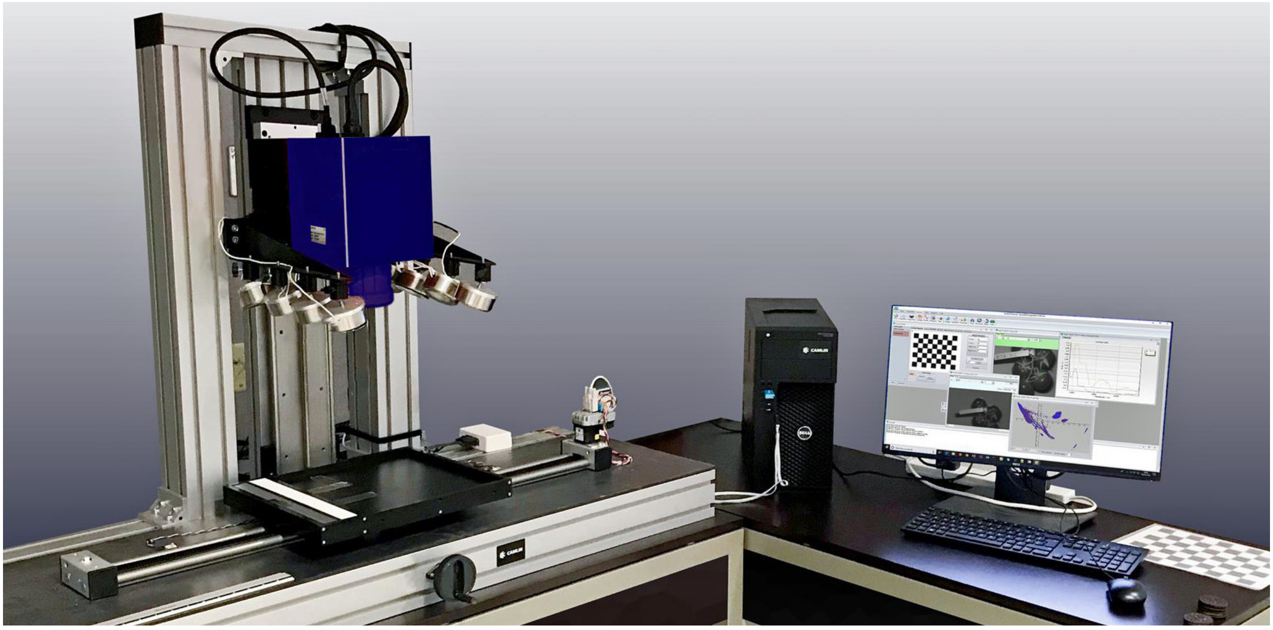
Desktop Scanner

The desktop scanner solutions are complete integrated solution that can simultaneously hold one or two spectral cameras and acquire data simultaneously to capture full spectral from 400 to 2500nm depending upon spectral cameras chosen. The systems are complete pre-configured scanners for area scanning over approximately A4, A3, and 1m x 1m sized areas by looking down onto target materials.

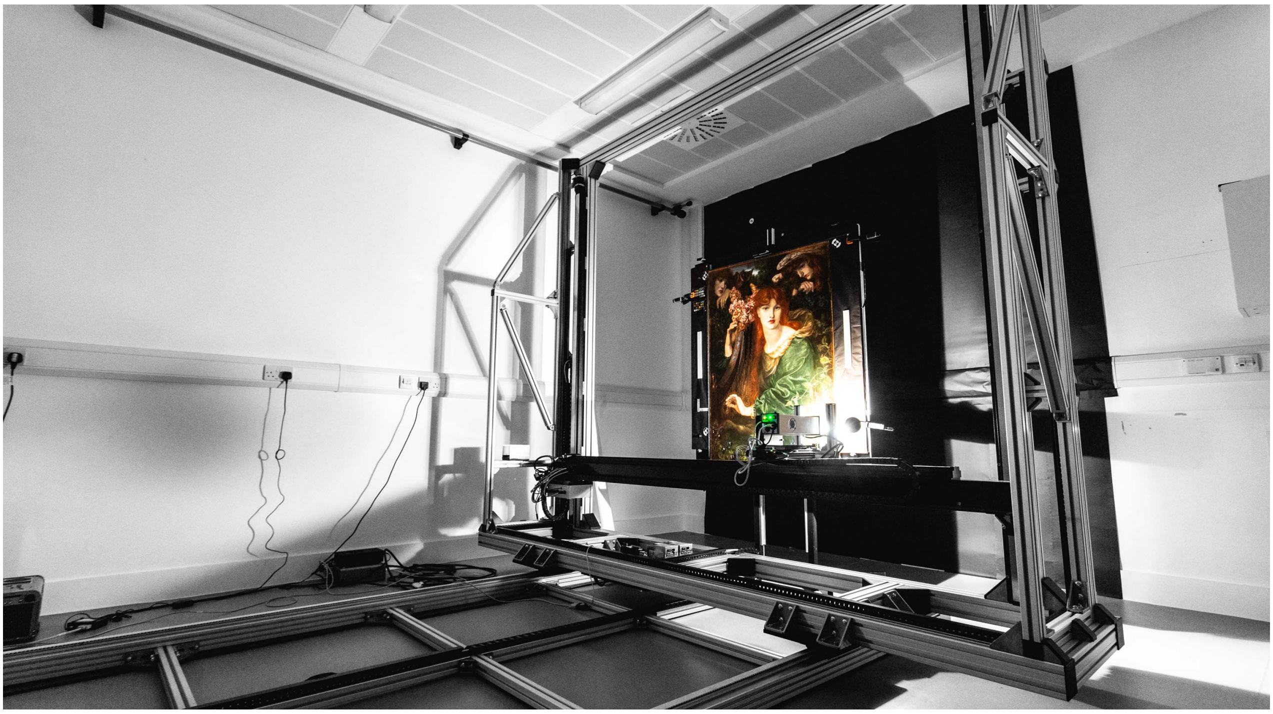
Ideal for document scanning in A4 and A3 sizes. All units comprise rigid camera support arm, precision height adjustable and with sensors for square pixel determination. Sample holders for documents, book, paintings and other objects. Automatic placement of white tile for 100% reflection measurement and focus tile to check image focus. The 1m^2 scanner has an optional high resolution 2-D camera option for conventional photography and survey use.



Parameter		Value		Units
Model	A4	A3	1m^2	-
Scan Area	250 x 300	300 x 500	1000 x 1000	mm^2
Scan Track Range	400	600	1200	mm
Scan Rate at. 100lfps		Depends upon the target pixel size, e.g. 5mm / s with 50µm pixels 50mm / s with 500µm pixels		-
Scanner Depth	600	600	1400	mm
Scanner Length	750	1200	1400	mm
Control Interface		USB2.0		
Power		90 to 260V 50 / 60		V AC Hz

2-D Large Area Scanning

Highly stabilised and monitored X Y (Z) scanning system for precision scanning of artworks and objects. Spatial step resolutions as fine as 5μm and optical resolution to macro mode and 25μm on target resolution across the full scanning area. Unique Curvature Monitor and compensation system to maintain on-target resolution, ensure focus, and accommodate for shape changes in the artwork across the scanning area.



Parameter	Value	Units	Comments
Scan Movement	X, Y, Zs, Zm	-	
Maximum Scan Area	2,500 x 2,500	mm^2	
Maximum Scan Pixel Area	88,000 x 88,000	Pixels	Up to 7.74GPix HSI images
Scan Step Resolution	5	μm	
Optical Resolution on Target	≥ 25	μm	Higher resolution available using a macro lens
X-Y Position Feedback	Encoded	-	
Zs, (Stand-off Stage)	0 to 3,000	mm	Other stand-off distances are available, please contact Clyde HSI
Zm, (Macro Stage)	± 75	mm	
Zm Control System	Real-time distance measurement		control system automatically adjusts for curvature of the artwork.
Spectral Camera Payload	≤ 50	kg	
Survey Camera	RGB Camera	-	16MPix, 100Mpix, 400Mpix options; interchangeable lenses

Zm Macro Stage

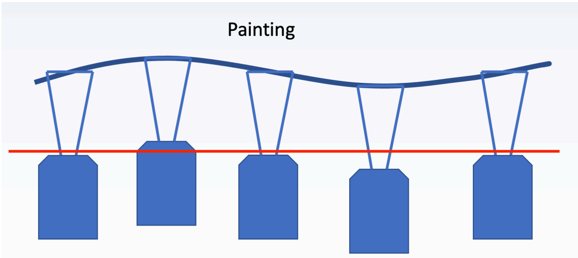
It is a common problem for paintings not to be flat and as such the measurement system needs to compensate for the surface shape. This measurement and possible compensation is important, as for any field of view the measured spot size changes with the distance between object and spectral camera. At the same time the depth of files may not be enough to keep all in good focus.

We do this by measuring the shape with a very low power, yet high precision laser rangefinder that measures the time-of-flight to target and back. This permits exceptional measurement capability. The Zm stage controller then adjusts the Zm stage stand-off to compensate for object curvatures and does this in real-time during the acquisition process.

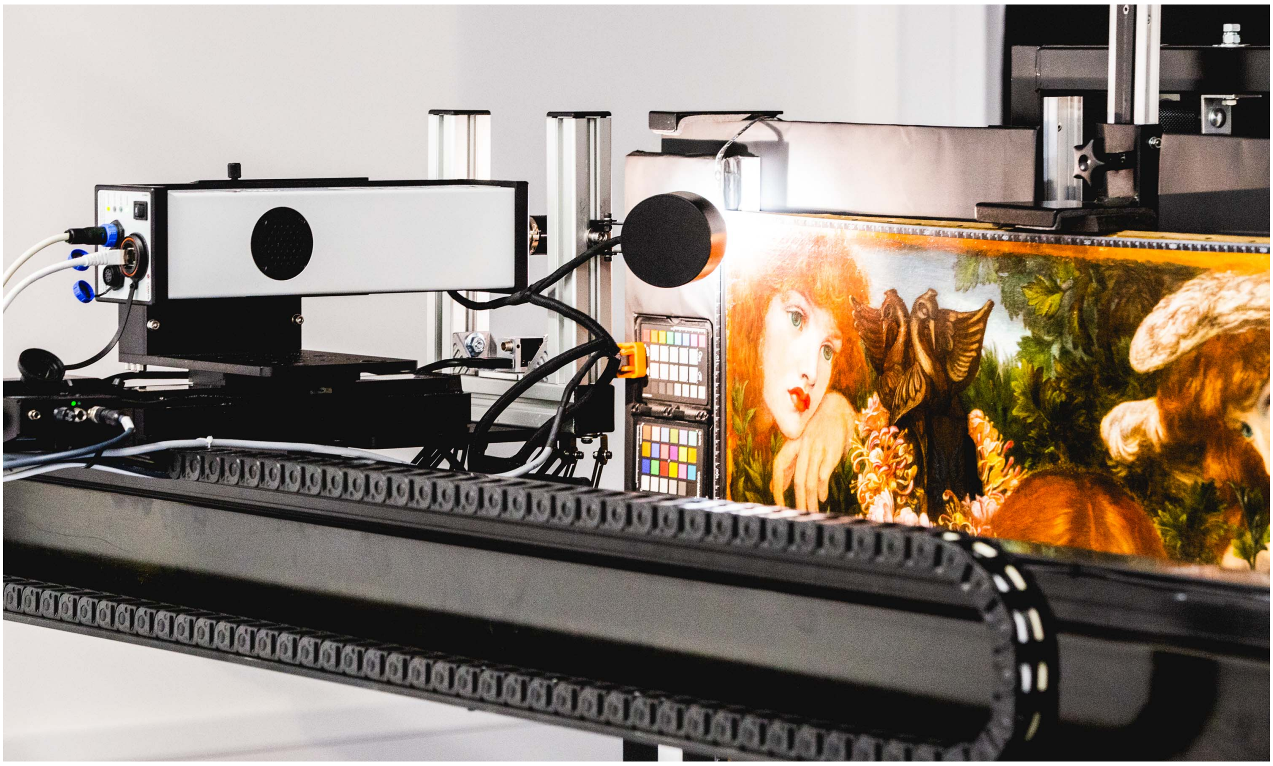
It maintains the target in focus with the correct spot size, and also provides a map of the artwork surface curvatures.

At the same time the laser rangefinders are use to monitor the, Zs, stand-off distance from target to ensure correct calculation of on target spot sizes and square pixels

Parameter	Value	Units
Accuracy	± 0.5	Mm
Repeatability	+/-0.3	mm
Range	0.05 to 50	m
Refresh Rate	50	Hz

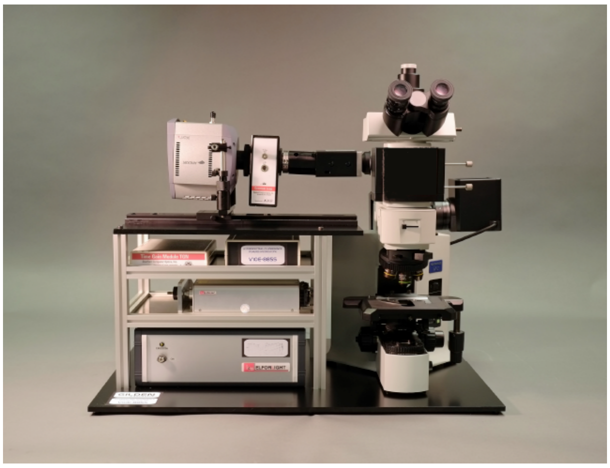


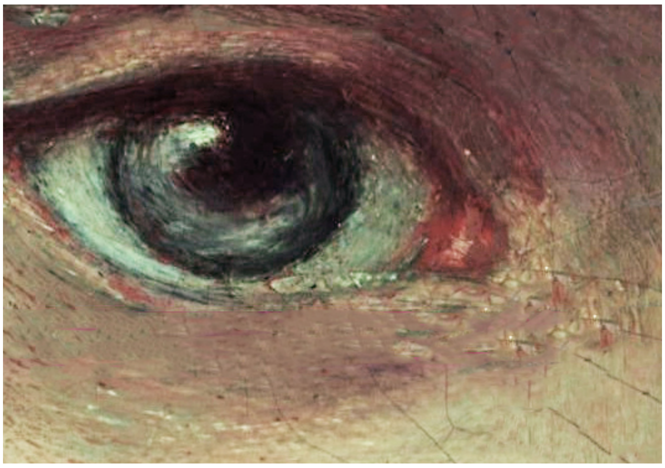
Therefore, the Zm macro stage with the laser distance sensors maintains on-target pixel size and focus across a non-flat object even though the degree of non-flatness that can be accommodated can be as high as ± 75mm from the nominal surface average.



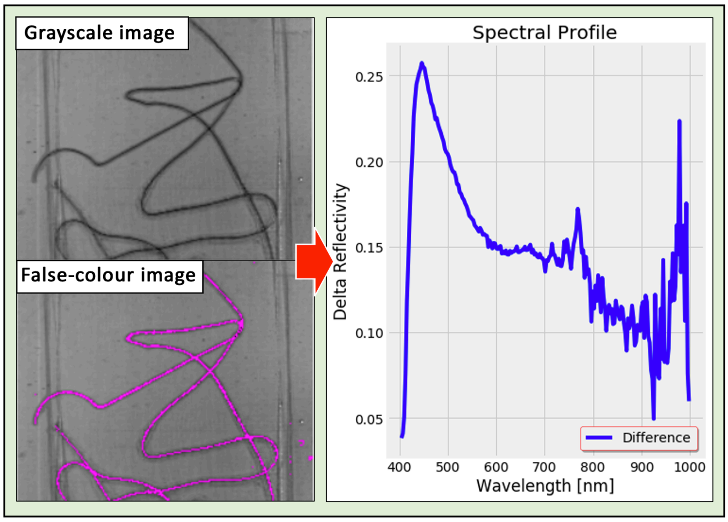
Microscope Scanner

The microscope scanner is a unique multi-modal capable instrument that permits both light and dark field microscopy, transmission microscopy as well as luminescence and polarisation studies for sample bi-refringence. Motorised nosepiece with wide spectral range objectives as well as automatic mode change facilities.





Parameter	Value	Units	Comments
Operational Modes	Reflectance, Transmission, Luminescence, Raman, Polarisation	-	Multi-modal operation with spectral correction and multi-strip mosaic imaging for large area high resolution scans
Spectral Range	400 to 1,700	nm	Broad spectral range ideal for colour and materials identifications needs
Spatial Resolution	≤ 1	µm	Interchangeble objectives using motorised nosepiece.
Spatial Range	300 x 300	mm^2	Large area highly stable motorised platform
Stage Repeatability	≤ 1	µm	



Spectral Cameras

A spectral camera is the core technology that's makes the art scanner perform as a hyper-spectral system. These cameras can measure reflectance or luminescence from the target object with both high spatial and spectral resolutions.

Parameter	VNIR-S	VNIR-HR	NIR-HR	NIR-HR+	SWIR	Units
Mode	High Speed Push-broom Scanning					
Spectral Range	400 to 1000		1000 to 1700		1000 to 2500	nm
Spectral Resolution	8	≤ 3	≤ 5	≤ 5	≤ 12	nm FWHM
Spectral Sampling Interval	1	0.7	3	1.5	<6	nm
Spectral Bands*	890/445/223	830/415/210	222	500	280	-
Spatial Pixels	1400	1600	320	640	384	Pix
Max. Line Frame Rate	120		344	300	400	lfps
Smile & Keystone Error	Sub-pixel across the spectrograph output field					-
Interface	GiGe				CL	-

* Spectral Bands depends upon the spectral binning conditions that have been set.

Objective Lenses

A spectral camera must have a suitable objective lens to define field of view and hence on target spot size. Examples of objective lenses and their FOV and IFOV are below. All lenses cover the appropriate spectral range and are mechanically stable such they can be locked into position on the spectrograph.

VNIR:400 to 1000nm

Parameter	Values (30µm slit)				Units
Focal length	17	23	35	50	mm
FOV	38.9	29.2	19.5	13.7	deg
Linear FOV	70.6	52.2	34.3	24.0	cm/m
IFOV	1.76	1.30	0.86	0.6	mrad
Linear IFOV	1.76	1.30	0.86	0.60	mm / m

NIR / SWIR: 1000 to 2500nm

Parameter	Values (30µm slit)			Values (15µm slit)			Units
Focal length	22	30	56	22	30	56	mm
FOV	24.6	18.2	9.8	24.6	18.2	9.8	deg
Linear FOV	43.6	32.0	17.1	43.6	32.0	17.1	cm/m
IFOV	1.4	1.0	0.5	0.7	0.5	0.3	mrad
Linear IFOV	1.4	1.0	0.5	0.7	0.5	0.3	mm / m

Software

Important to all measurements is how to collect the data, view it, and then pre-process and analyse the data sets. Not only is our software spectraSENS hyper-spectral software tool comprehensive, we have the resources to help you with the analysis challenges that might occur. At ClydeHSI dedicated scientists and engineers, with years of practical spectroscopy, machine vision, and artificial intelligence experience in both laboratory and industrial environments, are available to support your application needs.

Automatically make the hypercube dataset using spectraSENS software. This long established, stable software is available for all of our spectral cameras and provides an integrated system with our wide range of acquisition platforms including : linear translation, conveyor belt, 2-D, mirror and rotation scanners. Free-running or fully scripted modes are available. Data saved in camera RAW mode and fully ENVI compatible. Connection of meta-data and data files to SQL database facility. Alternatively, use the Acquisition SDK to develop your own application software for hyper-spectral measurements or export the data set to other analysis programs

Software Control Features	
Wavelength selections	Spatial Selections
Spectral resolution	Spatial Resolution
Frame rates and integration time per line image	Uni- or bidirectional scanning
Electron multiplying CCD gain and control (where applicable)	Live spectrum: by pixel or by area
Live signal counts for sample and illumination position optimisation	Waterfall acquisition display
Frame image and hyperspectral cube display	False colour images
Auto white and dark field measurements	Auto calculation: Raw data to %R
Spectral calibration	Export functions: images, spectra, etc.
File formats: BIL, BIP, ENVI Compatible	-

Display	Analysis
Waterfall	Spectral and Spatial
Image rotation	Principle Component Analysis
Spatial Selection	Spectral Angle Mapping
False Colour RGB (VNIR, NIR & SWIR data)	Support Vector Machine
Histogram and Levels Adjustment	End-member Classifications
Spectral Slicing	Partial Least Squares
Hi-Resolution RGB camera	Image Fusion

Other	
Target Referencing	Calibration Files: Spectral, Radiometric, Sample
Spectral Database (user populated for their application needs)	Geometric Corrections
Comprehensive data and image export facilities	Import of high resolution photogrammetry images and other image modes
Multi-track measurements	Mosaic fusion to join the tracks
Feature mapping	Geometric corrections
Selectable spatial down-sampling (if needed)	Rubber band selection, stages move to that position and ROI for scan
ROI selection and analysis from image	Fiducial alignment marks
Dual white tiles – 2m strips on each edge	Intensity calibration tile - grey scale
Wavelength calibration tiles in VNIR and SWIR ranges	Geometry corrections and alignment
Optional 400MPix photographic camera – sits in the system	Spectral and features database

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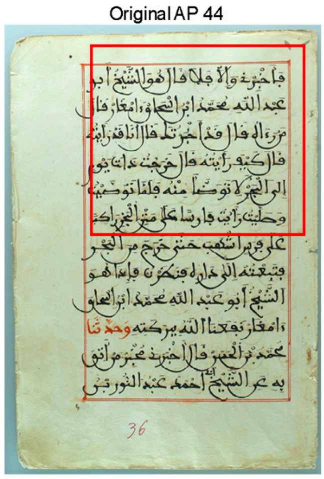
Example Hyper-Spectral Images and Spectra

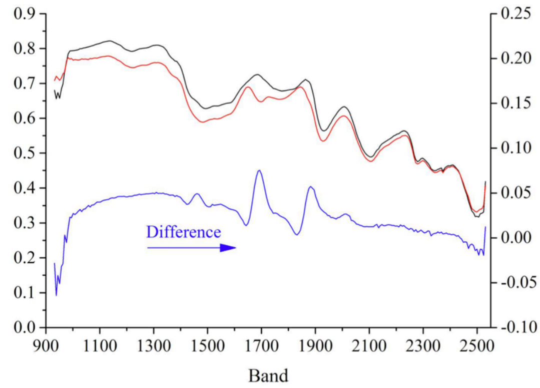
The understanding of the chemical and material properties of cultural heritage objects are a vital part to their successful conservation. The chemical imaging is determined by the optical spectra results form the image and these are used to process the data further. Until the development of hyper-spectral imaging and robust scanning systems, measurements had been made on a point-by-point or spot basis. Such point measurements provide limited spatial information rather than chemical distributions on the object and are time consuming and inefficient. Hyper-spectral imaging provides simultaneous optical spectra and spatial information in a time and light efficient manner. Such measurements allow visualisation and identification of specific chemical properties of the object.

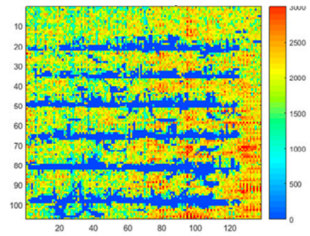
Quantitative Chemical Near Infrared Hyper-spectral Imaging of Islamic Paper

Multi-variate regression was used to provide quantitative information, particularly for starch sizing and the degree of polymerisation of cellulose. This was done using a calibration target of 105 samples and imaged in the SWIR (1000 to 2500nm) spectral region.

The main advantage of HSI in the NIR region over conventional measurements is the ability to produce chemical images that show the spatial distribution of chemical species in non-homogeneous materials.

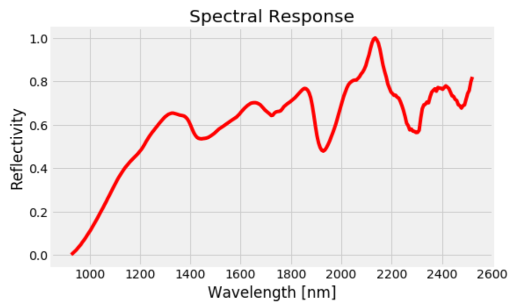


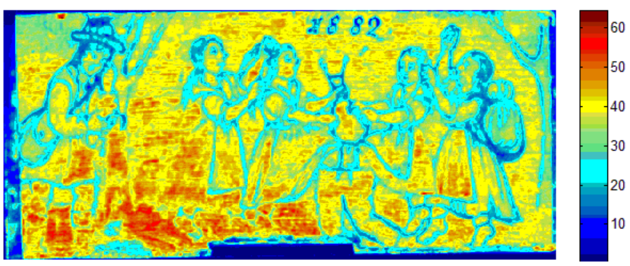


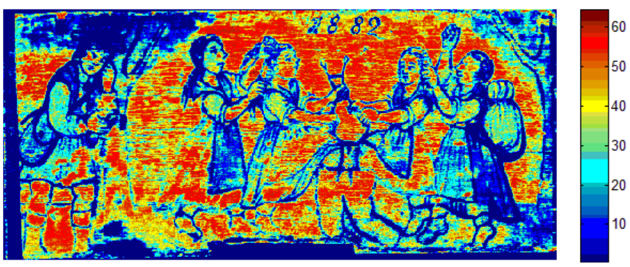


Material Characterisation of a painted beehive panel by advances spectroscopic and chromatographic techniques in combination with hyper-spectral imaging.

Retko, K., et al, Heritage Science 2020 8:120







Distribution of Dammar (1650 to 1750nm)

Distribution of wood features

La Ghirlandata by Dante Gabriel Rossetti 1873.

La Ghirlandata held by The Guildhall Art Museum of the City of London

High resolution mosaic image of La Ghirlandata measured on behalf of The Guildhall Art Museum

High resolution hyper-spectral mosaic image measured at UCL Institute for Sustainable Heritage facility at Here East.

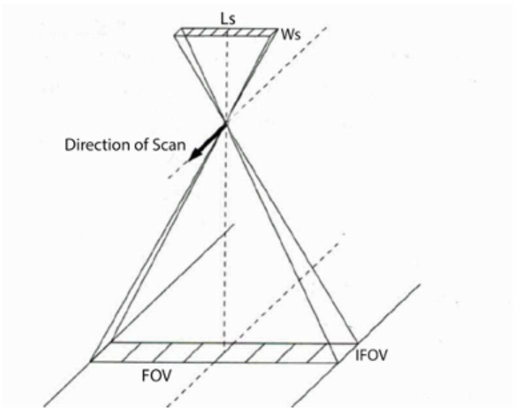
Hyper-spectral measurements made in both VNIR (400 to 1000nm, 2.5nm resolution) and SWIR (1000 to 2500nm, 5nm resolution) spectral ranges at optical spot resolution of 75µm over an area of 1240 x 850mm^2 resulting in an image of over 187M pixels. With each pixel containing optical spectra data representing its chemical signatures from the VNIR and SWIR ranges.

Measurements we made using push-broom line image strips with an overlap to ensure feature registration during the mosaic process. Image focus was maintained using the laser rangefinders built into the 2D large area scanner to drive the Zm focus stage.

Fiducial marks, “white tile” reference areas and colour checker panels were also automatically included into the measurement to ensure correct geometric registration and correction to reflectance values rather than raw data DN values.

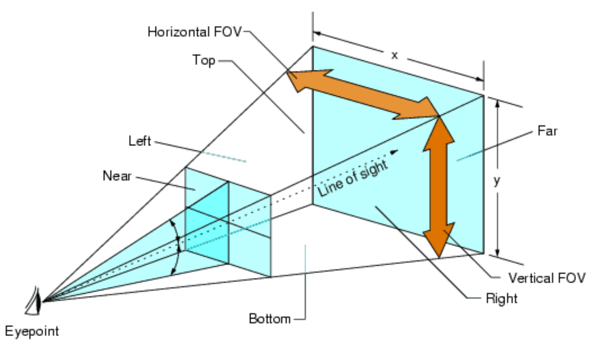
A note on Field-of-View and Depth-of-Field

Field of View



The Field of View, FOV, and the Instantaneous Field of View, IFOV, are characteristics of an imaging system that define the angular acceptance of the sensor to incoming light. They are therefore dependent upon the sensor and pixel sizes as well as the focal length of the objective lens being used. The angular FOV and IFOV are commonly expressed in degrees, while the linear field of view is a ratio of lengths. FOV can be measured in horizontal, vertical or even diagonally.

In a push-broom hyper-spectral imager, which is essentially a special version of a line-scan camera, the FOV describes the angular acceptance of the long axis of the spectrograph slit and is expressed in degrees. Similarly, the IFOV is also specified in angular form, often in milli-radians, to express the acceptance angle of the narrow dimension of the spectrograph slit. Of course, in some cases when determining the IFOV, the pixel size of the detector elements and binning conditions must be taken into account.
Thus, in push-broom HSI applications the lens focal length and the slit length define the relationship between linear FOV and the working distance. The linear IFOV is then defined from the working distance and the angular FOV. While the working distance is the distance from the back of the objective lens to the target.



$$\text{Aspect Ratio} = \frac{y}{x} = \frac{\tan(\text{vertical FOV}/2)}{\tan(\text{horizontal FOV}/2)}$$

At the same time the pixel view of the sensor is defined by this and for square pixels the IFOV alone the track much match the IFOV across the track.

It is convenient sometimes to specify the angular FOV in degrees as having a linear FOV of x-mm per m of stand-off distance, D.

How to calculate FOV and IFOV

To calculate the FOV ones needs to know the operating parameters of the hyper-spectral imager, that are:

- Focal length of the objective lens, f
- Spectrograph slit length, Ls
- Spectrograph slit Width, Ws

Thus, for the angular FOV and IFOV

$$AFOV = 2\tan^{-1}\left[\frac{Ls}{2f}\right] \text{ and } AIFOV = 2\tan^{-1}\left[\frac{Ws}{2f}\right],$$

and the linear FOV, and IFOV are:

$$FOV = \frac{Ls\,D}{f} \quad \text{and} \quad IFOV = \frac{Ws\,D}{f}$$

Example Results:

If Ls = 12mm, Ws = 0.03mm, f=23mm,

Then:
FOV = 29.2°, and Linear FOV = 520mm/m,

and

IFOV = 1.3mrad and linear IFOV = 1.3mm/m,

i.e. spot size of 1.3mm at 1m stand-off distance.

Depth of Field

The depth-of-field is the distance between the nearest and farthest objects that are in an acceptable sharpness of focus. Several factors affect this including, stand-off distance, focal length, aperture and the acceptable circle-of-confusion, CoC. Real lenses do not focus all rays perfectly, so a point source, even at best focus, is imaged as a spot. The circle-of-confusion defines what is considered as being the "acceptable sharp focus".

Acceptable sharp focus, at least in photography terms, depends upon visual acuity, viewing conditions, and the magnification from the original image.

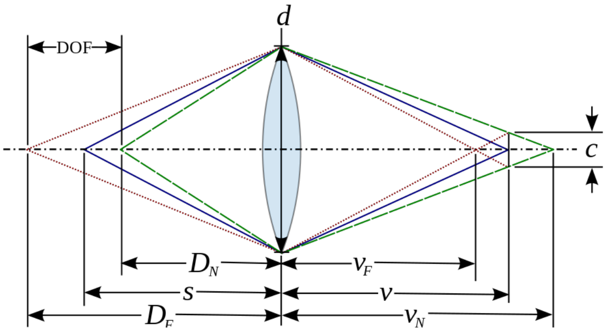
How to Calculate Depth-of-Field

A general approximation to depth of field is given by:

$$DoF = \frac{2NCD^2}{f^2}$$

Where:

N is the f-number of the objective lens,
C the acceptable circle of confusion,
D the stand-off distance, and
f the focal length of the lens.



Thus, the depth-of-field will increase with a smaller aperture, bigger f-number, or longer stand-off distance, or a shorter focal length lens. Of course, if the acceptable circle-of confusion is changed then depth of field will also change.

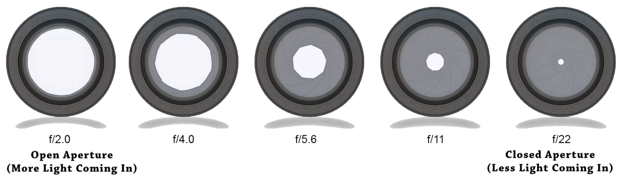
Example Depth-of-Field calculation

With a f=23mm lens, at a stand-off distance of 0.5m and a f/2.5 spectrograph and a CoC of 30μm, then the DoF is about 71mm. However, if the spectral camera lens is stopped down to say, f/4, then the DoF increases to just over 113mm. Increasing the f-number means bigger depth of field, but there is a consequence associated with light collection.

Collected Light

A consequence of stopping down the aperture to increase the depth of field is a reduction in light collected by the spectral camera.

Since light collection varies as $1/(f/\#)^2$, decreasing the f-number is one way to collect more light. However, by doing so one decreased the DoF. For this reason there needs to be a compromise between DoF and light collection, unless the illumination source and reflected light from the target is sufficiently bright to allow such apertures to be used.

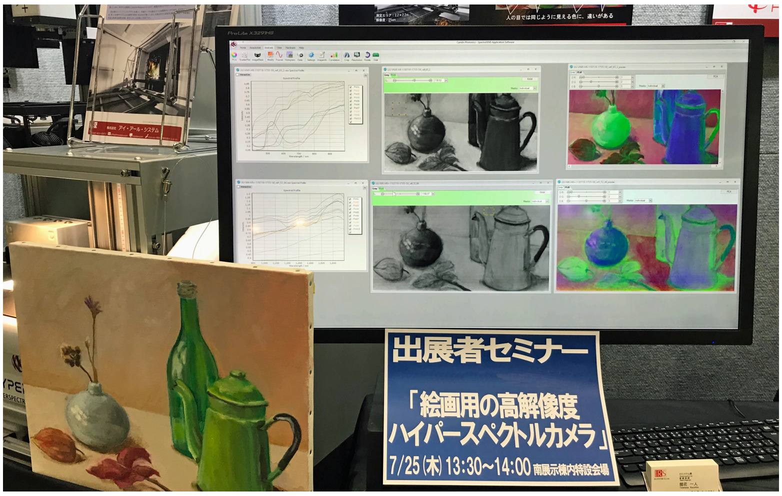


Low F/# lenses collect more flux, but the lens aberrations determine the quality of the collimated output. These aberrations go up rapidly with decreasing f/#. Though more light is collected by a very low f/# lens, the beam produced is imperfect. Even for a point source it will include rays at various angles, far from the collimated ideal.

The Hyperion Hyper-Spectral System is a Solution for Art Measurements

Hyperion hyper-spectral systems are feature packed with high-spatial and spectral resolution and options that measure with minimum illumination requirements to provide superb signal-to-noise ratios even at high -speed scanning modes.

The spectraSENS software package seamlessly integrates all components to make a time and cost effective measurement system that can be readily deployed for a wide range of document and artwork studies. Each system can be upgraded at any time with additional scanning systems or hyper-spectral cameras by the user themselves.



Painting by YuYu, 2019

Hyperion HSI Systems are optimally designed for art and art conservation measurement to enhance the knowledge of the researcher and conservator.

Other HSI Applications

Hyper-spectral imaging uses the optical spectrum of a target material and this is used as a "fingerprint' to visualise and identify materials, their distribution in a target scene and, also when calibrated their concentrations.

At ClydeHSI we we successfully delivered hyper-spectral imaging system into many application areas.

Food and Food Security

Smart analytical tool for food and agricultural product inspections. Assessment of moisture content, protein, material homogeneity, or foreign body detection as well as package seal integrity.

Forensics

Hyper spectral aiming can reveal altered text documents, body and other fluids at scene of crime and on materials, as well as visualising and identifying trace evidences. Examination of bruising and wound age profiling.

Recycling

NIR Hyper-spectral imaging can differentiate between different types of plastic material as well as construction and demolition waste regardless of their colour.

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