**IMSPECTOR** *Imaging spectrographs*

# User manual

## Standard and Enhanced OEM models

Spectral Imaging Ltd
(September 2008)

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

## Contents

Specim ENHANCE YOUR PERCEPTION
Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

# Imaging spectroscopy

Spectrometers or spectrophotometers are usually able to measure optical spectrum from a surface area as one point. This is done either with one detector scanning the spectrum in narrow wavelength bands or with an array detector, in which case all the spectral components are acquired at once. If one desires to measure the spectrum at several spatial locations of a surface, the target under examination or the measuring instrument has to be mechanically scanned.

An imaging spectrometer instrument (or spectral imaging instrument), based on an imaging spectrograph like the *ImSpector* can be defined here as:

**'an instrument capable of simultaneously measuring the optical spectrum components AND the spatial location of an object surface'.**

Technically it is not possible to measure simultaneously spectral information across a 2 -dimensional surface matrix, because this would lead to a four dimensional information space (X,Y -coordinates, wavelength and intensity). This is obviously impossible to realize with standard two dimensional detectors which can register only position and intensity of radiation at a time. This leads to the idea of measuring the spatial information across a line only (X-axis with specified length and small but finite width) and the spectral information (wavelength and intensity) for each point (pixel) in this line (Fig. 1.1.). A 3 -dimensional information space results that can be measured with an area (matrix) detector array connected to a dispersive, stationary spectrograph module. One dimension of the detector now constitutes a spatial line image and the other dimension measures the spectrum for each line pixel. This is the operating principle of the *ImSpector* imaging spectrograph. In other words, **the *ImSpector* converts an area monochrome detector (camera) to a spectral line imaging system**.

There still remains the task of scanning the surface in Y -axis dimension as a function of time, but this is much easier to accomplish than XY-scanning and is not always even necessary. In some applications the movement of the object (process stream, web...) automatically forms the other spatial dimension.

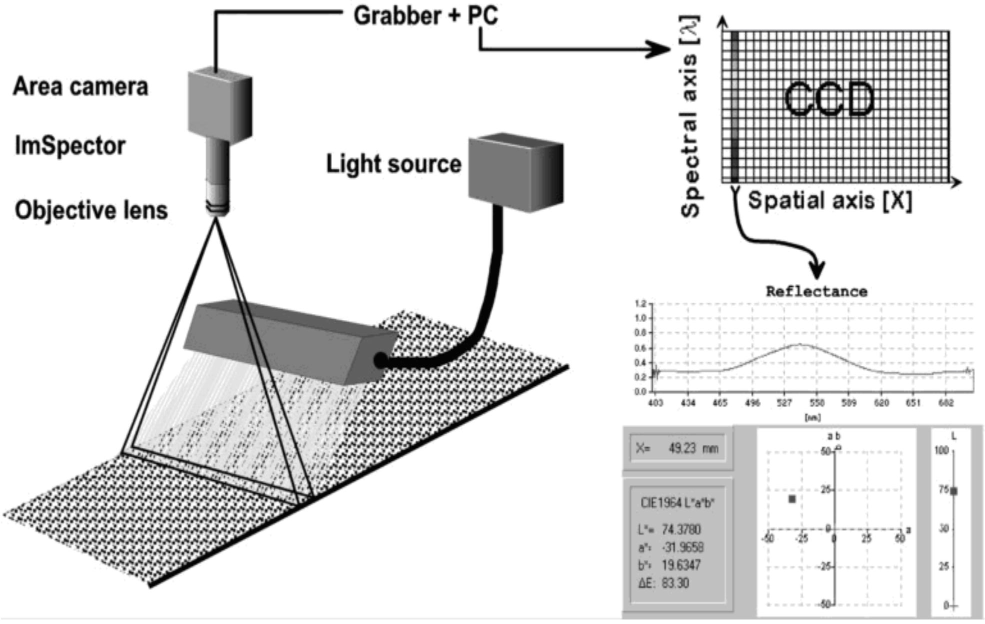



*Figure.* Spectral imaging across a two dimensional plane. An area detector is able to register position in the X -coordinate axis, wavelength and intensity. The Y -axis of the plate is measured by acquiring line images while moving the plane in Y-direction.

# Advantages offered by spectral imaging

Some advantages of spectral imaging are obvious: reduced measurement time and simultaneous measurement across a line area without need for scanning mechanics. In many applications several single point instruments can be replaced by one multichannel imaging spectrometer using objective or multilegged fibers, thereby saving both in the instrumentation cost and in the amount of mechanics and required space. The small size of the spectrograph and commercially available CCD cameras can make many measurements practical for the first time. Multipoint measurement with a single instrument eliminates the problem of calibration mismatch between separate sensors.

On the other hand, spectral imaging produces a large amount of data, and therefore, particularly process applications may require sophisticated data readout and processing, like on-chip binning and addressable line (=wavelength) readout for minimizing the amount of data and DSP circuits for fast on line processing.

The ***ImSpector*** is designed both for industrial and research use. It offers specific advantages in cases where

- The user needs to upgrade an existing industrial or research monochrome camera system for detection of color or other spectral features. The ***ImSpector*** makes it possible to utilize all the existing system components.
- The user needs to precisely determine color or color difference across a line with a good spatial resolution and with a standard method, like color coordinates.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi



- In comparison to point color spectrophotometers the ***ImSpector*** provides far better spatial resolution and simultaneous measurement across a large number of points.
- In comparison to RGB color camera the ***ImSpector*** provides better color resolution, full compensation for light source color temperature changes and full spectral information with flexible wavelength selection by software.
- The application requires broader than visible (color) wavelength range, like 400-1000 nm. RGB camera is limited to three fixed wavelength bands in 400-700 nm.
- The user needs to measure color or other spectral features simultaneously across several points by means of fiber optics.

# ImSpector dispersing optics

Reflection and transmission gratings are currently used in various dispersive spectrometers worldwide. In the practical realization of imaging spectrographs for two dimensional CCD there was difficulties due to the off-axis construction of typical instruments (Littrow or Czerny-Turner configurations). These inherently have some amount of geometrical aberrations, like keystone and smiling, which result in reduced imaging quality.

Therefore *ImSpector* employs a new direct sight optical configuration and a transmission grating. It is based totally on transmissive optics.

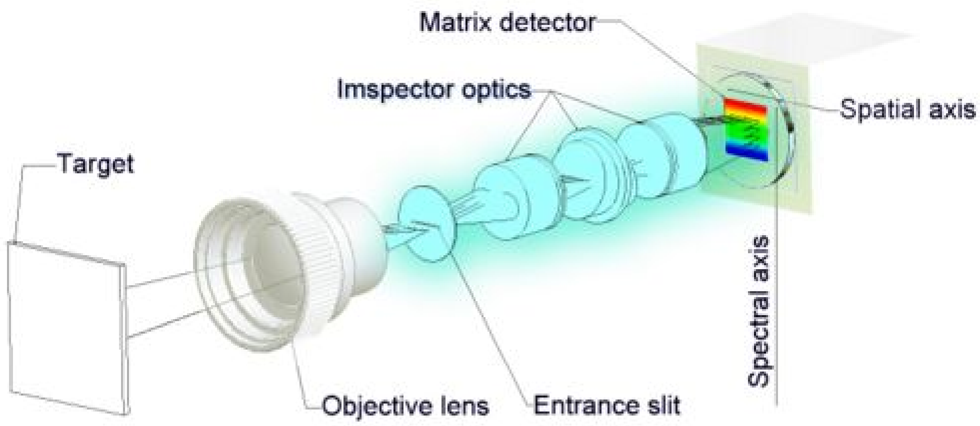



*Figure*. Schematic of the *ImSpector* imaging spectrograph showing also the simultaneous spatial (line) and spectral mapping with an area detector.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

# Optical properties of the ImSpector Standard and Enhanced version

Generally the quality of a spectrograph can be described in terms of its spectral range, resolution, nonlinearity, S/N ratio (straylight), diffraction efficiency and stability. An imaging spectrograph has also the spatial axis to consider. The parameters needed in characterising spectral imaging system are:

1. Spectral resolution (also at different spatial locations across the detector plane),
2. Spectral linearity (and it's variation at different spatial locations),
3. Absolute efficiency of the optics (throughput) and diffraction efficiency of the grating,
4. Smiling or curvature of the slit image on the detector plane,
5. Vignetting across the detector plane (spatial flatness of throughput),
6. Astigmatism (especially in fiberoptic systems),
7. Straylight (S/N), ghost line and ghost image properties.
8. Wavelength stability.

General ***ImSpector*** optical specifications are shown in **ImSpector Specifications**. The main difference between Standard and Enhanced series spectrograph are:

- Standard series spectrograph should be used with CCD detector having smaller than 9 mm long spatial axis (slit length). Enhanced series spectrograph has 14 mm slit therefore making it possible to use longer spatial axis detector.
- Standard series spectrograph has small amount of smiling (curvature of spectral line) and keystone (difference in magnification in different wavelengths)
- Mechanically Standard series spectrograph's have straight optical axis, Enhanced models have small angle after the grating.

The *ImSpector* imaging spectrograph can be implemented to cover a spectral range in the UV, visible and in the near infrared region up to 2500 nm. Standard versions are: UV4 (200 - 500nm), V8 (380 - 800 nm), V10 (400 - 1000nm), N17 (900 - 1750 nm) and N25 (1000 – 2500nm).

The spectral resolution of the spectrograph depends on the width of the entrance slit and linear dispersion produced by the spectrograph optics. Minimum limit for the spectral resolution is set by the imaging capability of the optics (point spread size).

The slit dimensions also define, together with lens focal length and distance from lens to object, the length and width of the imaged scene line. The input slit is lithographically manufactured on a glass substrate. Thus, there is no physical hole to the inner parts of the spectrograph and the glass prevents dust particles from entering the actual slit surface. Special process is used to make both sides of the slit optically "black". This prevents reflections and reduces straylight both in front the slit (objective side) and inside the spectrograph.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

The ***ImSpector*** has two high quality lenses that are used to collimate light to the dispersing PGP element and to focus light to the detector surface. These lenses are specially designed for a wide field of view and a low f-number, and they provide excellent image quality by reducing several common aberrations. There is no vignetting and the field curvature is minimized.

There are no adjustable or moving parts inside the spectrograph but spectrograph components are locked permanently.

### Order blocking filter

Some of ***ImSpector*** models (e.g. V10, V10E and N25E) produce a wavelength range larger than one octave. Order blocking filter is needed to prevent the second order spectrum from overlapping with the end of the first order spectrum.

## Principles for camera selection

Many of the *ImSpector* Enhanced spectrograph performance characteristics exceed those of standard CCD cameras. Therefore in many measurement applications the limiting component will be the camera. Camera selection depends on application requirements, but the following list shows basic criteria for the selection of a proper camera for imaging spectroscopy.

- ***ImSpector* Standard** models are designed for the 2/3" (6.6 x 8.8 mm) detector. The shorter axis is defined to be the spectral axis. It is also possible to turn the spectrograph 90° for a broader spectrum. If a ½" (4.6 x 6.4 mm) camera is used, the longer axis should be used as the spectral axis. This reduces the size of the available spatial image. Larger than 2/3" cameras can of course be used, but the image does not cover the whole detector.

- ***ImSpector* Enhanced** models are designed for detectors having 14 mm spatial axis. However, the spectral axis is still only 6.6 mm in length.

- The camera should have a sensitive detector either with a proper window material or without a window. Especially in the blue part of the spectrum, the combination of low output from halogen lamp and the poor detector response can result in unsatisfactory S/N ratio. If a NIR spectrograph is used the NIR blocking filter sometimes present in many CCD cameras should be removed.

- A cooled or temperature stabilized detector is recommended to allow long integration times in a low light level application and to minimize temperature induced offset variations in variable industrial environment.

- In demanding spectroscopic measurements, a digital camera with pixel synchronized output gives better S/N than a camera with common CCIR standard or other analog video output.

- The camera should have sufficient amount of pixels to satisfy required spectral

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

and spatial resolutions. One should always consider the discrete sampling nature of the camera array while evaluating the true spectral and spatial resolution achieved in measurements.

- It is recommended to have as large a pixel size as possible to maximize signal per pixel. However, this is sometimes in contradiction to resolution and price requirements.

- Sufficient dynamic range is essential particularly in precise color and analytical measurements. As a rule of thumb 8 bit dynamic range allows color difference resolution about 1 ΔE (typical capability of human eye), 10 and 12 bits lead to ΔE values of 0.3 and 0.1 … 0.05, respectively.
- **NOTE 1**: There are some CCD detectors which have a thin coating on the surface of the chip. In spectroscopic measurements, this coating can introduce dim interference fringes that may be visible at the final image. These do not have any effect on measurement.

- **NOTE 2**: The ΔE (delta E) is a value that giver difference (or separation) of two colors presented in L*a*b* color co-ordinates. The L*a*b* is calculated from the spectrum in visible wavelength region and it simulates the human perception of color..

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

# Principles for objective lens selection

The *ImSpector* has been designed to accept any standard C -mount objective lens. The importance of the quality of the lens should not be underestimated. A number of lens properties affect directly to the measurement result and must be considered when evaluating lens: These are:

- Modulation Transfer Function (MTF) and amount of straylight affects how well the lens reproduces modulation (contrast) or brightness differences of the original object.
- Spectral transmission and suitability to near infrared range if NIR spectrograph is used. Transmission may be reduced by absorption and reflections by the optical materials that lenses are made of. Also the standard lenses have been designed to use visible light, and the colour correction for infrared wavelengths has been ignored.
- Spatial uniformity of throughput: this may be deteriorated by the vignetting in the image lens if the lens aperture is not large enough for the detector size used.

| Focal length of objective lens | Angle of View at spatial axis using 2/3” CCD | Object size at 1 m distance |
|---|---|---|
| 8 mm | 58° | 1.11 m |
| 12.5 mm | 39° | 0.7 m |
| 16 mm | 31° | 0.55 m |
| 24 mm | 20° | 0.35 m |
| 35 mm | 13° | 0.23 m |
| 50 mm | 10° | 0.18 m |

*Table.* The angle of view and the size of object at 1 m distance using different focal lengths.

Other parameters to consider are of course the focal length and the f-number of lens. The focal length affects the image size and angle of view. See Table above.

The f-number of the ***ImSpector*** **Standard** series spectrograph is F/2.8m and ***ImSpector*** **Enhanced** series spectrograph F/2.4. This is “slow” compared to the best F-numbers for common lenses (F/1.2 … F/1.8). In practice this means that the actual limiting factor of the system throughput is most often the spectrograph and no advantage can be gained by using faster f-number objective than that of the spectrograph. In fact, using a lower f-number just overfills the spectrograph numerical aperture and can cause unwanted reflections and increased straylight inside the spectrograph.

- A CS-mount objective, although it shares the same thread pitch and diameter is not directly compatible with C -mount. The flange-back length of a C -mount is 17.53 mm which is 5 mm longer than that of CS -mount.
- Many C -mount objectives are designed only for the smaller ½” detector size. These should not be used with 2/3” or larger detectors.

**Multipoint fiber optics**

There is an option to use multipoint fiber as input optics. Usually there is from ten to hundred channel fibers used. With this kind of setup it is possible to have very large or distant target area and get separate spectrum for each channel with one spectrograph setup.

# Guidelines for suitable illumination

In conventional B/W imaging all wavelengths are registed by one pixel, instead in imaging spectroscopy each pixel registers only a small fraction of the spectrum (commonly 1 – 5 nm). This causes the need for efficient light source.

Source spectral output should be right for wavelengths that will be acquired. The most common light source type is Halogen lamp. There are several options of light sources at market, with different forming, diffucing or focusing. Illumination has to be always

Some light source examples

- Halogen (thermal sources, various sizes and shapes)
- Deuterium (UV)
- Black lights (UV-A and UV-B)
- Gas discharge lamps (fluorescence lamps, Xenon lamps pulsed or continuous)
- LED (white, RGB, limited usability)
- Sun

The ImSpector is basically a line imaging instrument, and thus a fiber optic lightline is very well suited illumination source for such system. Lightlines and light sources for these are available from several manufacturers.

The following notes provide a check list to achieve proper alignment and performance with a system consisting of halogen light source with a fiber optic lightline and a ImSpector/camera unit with a fore lens. Alignments and adjustments are easiest to do when live image from the camera is available.

Check that the fore lens numerical aperture is set to the same numerical aperture than the used ImSpector spectrograph has. This assures that the lens will not limit the system throughput.

If the application is in the visible region, and the light source is equipped with a standard EKE halogen lamp, adjust the light intensity knob in the light source to its maximum for best signal in the blue region. If the application covers near infrared (NIR) region too, and no NIR blocking filter is used in the light source, it is recommended to set the light intensity knob to 75-80% of the maximum.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

Usually it is appropriate to illuminate at 45 degrees and image at 90 degrees with respect the target surface (as shown in Figure 1).

If the target surface is 3-dimensional (has large passline variations), it is better to use smaller angle between the illumination and imaging. However, care should be taken that specularly reflected light does not get to the spectrograph.

The fiber optic lightline can be used without or with a cylindrical lens. If the lightline can be placed close to the sample surface, light intensity will be usually sufficient and very uniform without the lens. With the cylindrical lenses, the light becomes collimated in a narrow line. The width of the line depends on the separation between the lens and the fiber optic line.

Having a white calibration sample as a target, adjust the illuminated line width so that the highest signals in the image are close to the maximum range in the system. However, be sure that the signal is not saturating in any of the image pixels.

If there tends to be too much light, it is recommended to make the light to spread over a larger area than e.g. reduce the lens numerical aperture. Spreading the light over a larger area will make the illumination more uniform.

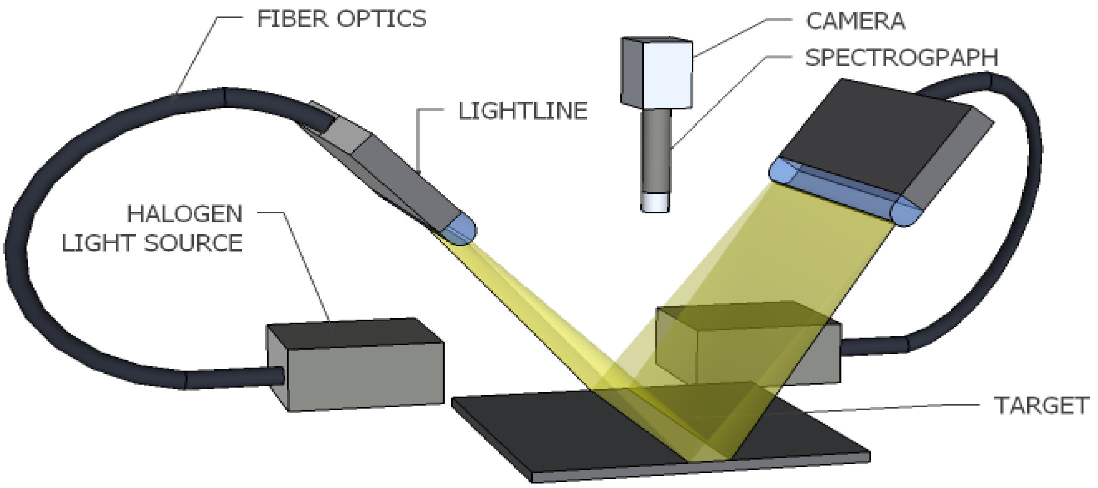



Figure. A typical spectral imaging setup with fiber optic lightline.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

## Spectral flattening filters

When using spectrographs the usual behaviour of system is that it is working better at certain part of the wavelength range and the SNR tend to decrease at some other regions of the wavelength range. Due to the light source radiance, detector response and systems instrument function it is sometimes worth of even necessary to use filters to balance the system in order to increase the SNR at some wavelength bands and improve the use of dynamic range of the detector.

*Imspector* Enhanced series model has an internal mount for 32mm diameter filters between objective and spectrograph

## Shutter

*Imspector* Enhanced series model can be equipped with a shutter. With shutter it is easy and fast to acquire dark frames. See 'Offset created by dark current'

# Camera Integration

## General

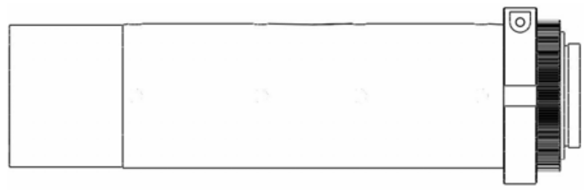
The ***ImSpector*** **Standard** and **Enhanced** spectrograph models***)** can be connected to any C -mount camera. The optics is factory adjusted to have the back focal length (BFL) of 17.53 mm that standard requires. Mounting to the camera can be accomplished by following the next procedures step by step. It is recommended to use a common baseplate under spectrograph and camera to maintain alignment if used in high vibration environment. With the E -series spectrograph one needs to take into account the small angle between the front and back side of the spectrograph.

Due to difference in camera mechanical properties no universal solution exists and following examples serve are guidelines only.

***) N25E can be mounted only with M42x1 thread.**

# Standard version

The Standard ImSpector model is tubular with removable C-mount.



## Camera attaching procedure

| | |
|---|---|
|  | Remove the protecting cap from the rear C -mount. |
|  | Remove the rear C -mount adapter plate from the ImSpector spectrograph using Hex 2.0 screwdriver. Beware not to touch the now exposed lens surface. |

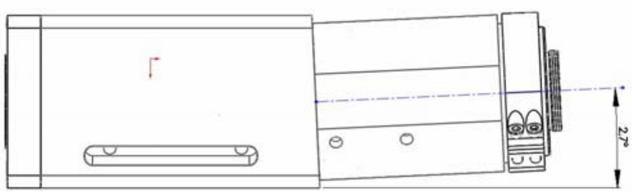
Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

| | |
|---|---|
|  | Attach the adapter to the camera's C -mount. Tighten the adapter firmly to the camera. |
|  | Put the spectrograph to the adapter and tighten the locking screw slightly.<br><br>After assembly, the camera and the ImSpector spatial axis should be aligned to CCD rows. Hence, before tightening the locking ring firmly, please check the paragraph "Axis alignment procedure" in this manual. |

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

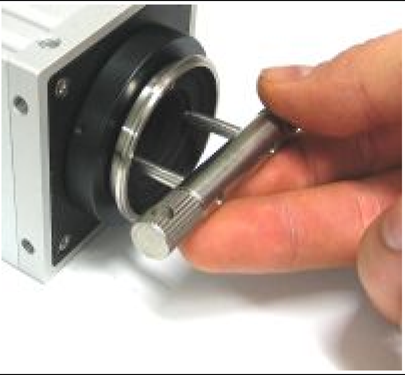
# Enhanced model

The Enhanced model has small angle between the front part and the back part of the spectrograph. This angle is defined in the attached drawing. (V-series 2,7º, N-series 4,2º)




### Camera attaching procedure

| | |
|---|---|
|  | Remove the protecting cap from the rear C -mount. |
|  | Remove the rear C -mount adapter plate from the ImSpector spectrograph by turning hex screws until locking ring parts are loose. Beware not to touch the now exposed lens surface. |

| | |
|---|---|
|  | Attach the adapter to the camera's C -mount. Use the special wrench tool that is provided with the spectrograph to tighten the adapter firmly to the camera. |
|  | If necessary, the C -mount can be locked to the camera using a small hex screw (M3x3 mm). For this reason there is a M3 thread in the C -mount adapter plate. |
|  | Connect ImSpector to the camera by placing locking ring parts and tightening hex screws slightly.<br><br>After assembly, the camera and the ImSpector spatial axis should be aligned to CCD rows. Hence, before tightening the locking ring firmly, please check the paragraph "Axis alignment procedure" in this manual. |

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

# Camera removal

It should be emphasised that the C -mount does not return to the same angle after removing and re-mounting the camera to the *ImSpector*.

**NOTE:**. The spectral and spatial re-calibration is required whenever the camera head is removed from the *ImSpector*!

# Objective lens

The *ImSpector* front objective adapter can accept any C -mount objective lens. Mechanical back focal length of the objective should be 17.53 mm. With proper adapters it is possible to use objectives with CS -mount, d -mount, T -mount or Nikon bayonet.

- The objective lens should be focused on the measurement surface using a test plate (black and white stripes).
- The F/number of the objective lens should not be set lower than that of the spectrograph even if possible. There is a risk of excessive stray light caused by overfilling the spectrograph NA.
- Standard objective lenses are optimised for visible wavelength range. There are also lenses which are designed for the NIR region. These guarantee the best performance with spectrographs covering the spectral region above 700 nm. Please contact Specim for manufacturer information.
- There is an input slit visible when the front optics is removed ! Be careful to prevent dust, other foreign particles and drops of water from getting on the input slit. Do not make finger prints on the input slit. It is best to put the special protective cap (supplied with the ***ImSpector***) in the C-mount immediately after the objective lens is removed.

# Disassembling the ImSpector -optics

There are expensive and delicate optical components inside the spectrograph. These could be permanently damaged by improper handling. Please, do not open the *ImSpector* spectrograph. Take all necessary precautions to prevent dust, liquid or vapour penetrating the instrument while camera or objective port is open.

In case of need for any repair, please contact your local distributor or Spectral Imaging Ltd. directly.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

# ALIGNMENT AND CALIBRATION

## Axis alignment procedure

After the assembling procedure, the camera and *ImSpector* should be aligned so that the spatial axis of the spectrograph is parallel to horizontal pixel lines of the camera.

This can be done in several different ways but usually the following procedure gives the best result. We presume here that the camera and monitor horizontal axis are defined to be the spatial axis of the image, so that the spectrum is dispersed vertically.

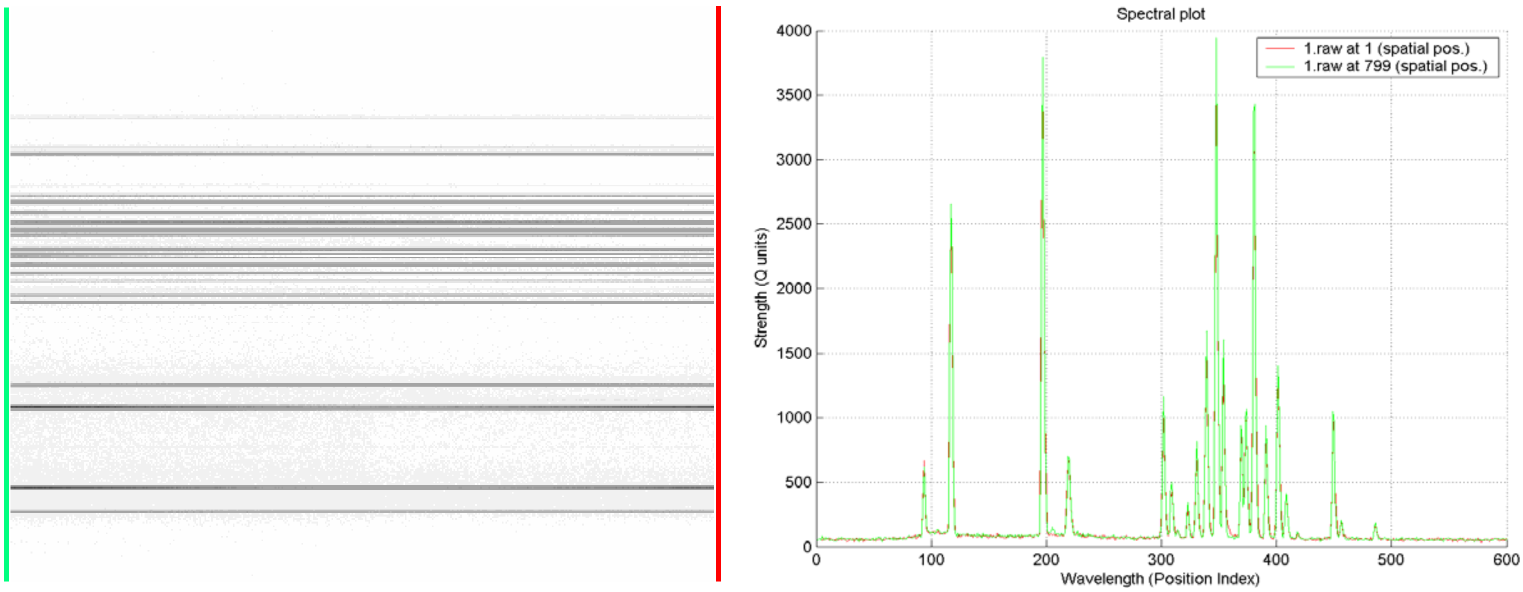
1. Remove the front objective lens.

2. Point the spectrograph and camera to a light source giving narrow spectral lines or place a light source in front of the spectrograph slit. Good sources for this are neon lamps, Hg -lamps and common fluorescence lamps. An optional integrating sphere (with the spectral lamp inside) could be also used to have more uniform illumination across the slit.

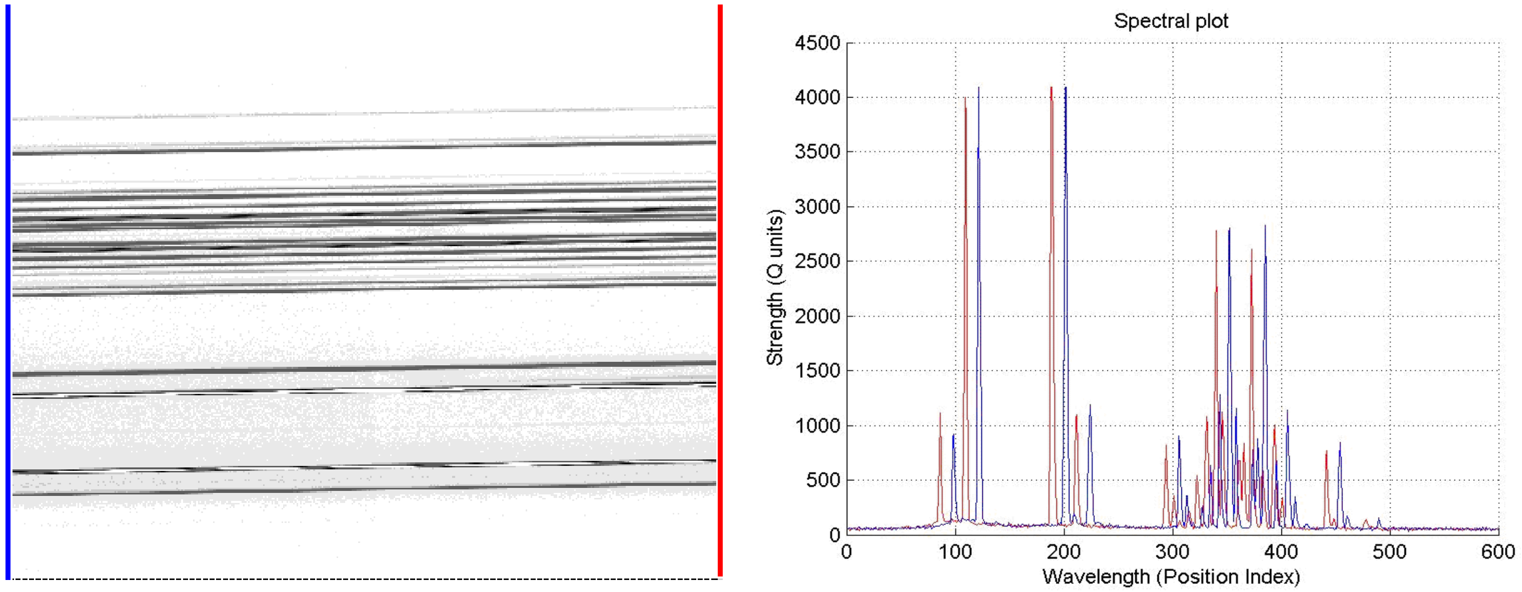
3. Look at the image at a video or PC screen. Narrow lines should be seen crossing the screen from left to right (*Figure* below). These lines should be aligned horizontally along the detector rows so that the lines are at same the height at the left and right side of the detector. Note that the direction of wavelength scale depends on how the spectrograph and camera are attached. You can change this by turning the camera 180°.
4. The alignment is done turning the camera with respect to the spectrograph.

It is recommended to use a special software to look at two spectral profiles, one at the left and one at the right side of the image. The alignment is perfect when the spectral line so these two spectra overlap perfectly. (figure below)

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi




Axis alignment is good. Spectral profiles are overlapped.




Axis alignment is bad. Spectral lines are tilted and profiles are separate.

*Figure.* HgAr spectral lamp lines and spectral profiles at left and right edge.

Note: Images are inverted.

ENHANCE YOUR PERCEPTION

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland

Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

# Back focal length adjustment

The *ImSpector* spectrograph has been adjusted for standard C -mount back focal length (BFL) which is 17.53 mm. If the camera CCD detector surface is not exactly at this distance it is not possible to simultaneously achieve the best possible spectral and spatial focus and resolution. The BFL can also change due to adding an order blocking filter or adding or removing a NIR blocking filter. This results in a change in optical path length between spectrograph and CCD. If the BFL is not within specified tolerances it may cause a situation where spectral and spatial images are not properly focused at the exactly same image plane.

Best way to verify that BFL is ok is to use a light source with narrow spectral peaks like spectral calibration lamp or standard fluorescent lamp.

- Place the lamp very close to the input slit and without the front objective attached. The whole numerical aperture of the spectrograph should be filled. If integrating sphere and spectral calibration lamp is available the adjustment can also be done using a front objective looking inside the sphere.
- If the BFL is correct the observed spectral line widths are within specified spectral resolution values (refer to test report shipped with the spectrograph). If the BFL is erroneous the line widths are much broader than specified values.

Wrong BFL

Spectral peaks are fuzzy and low intensity.

(image captured with *Imspector* model V8E and Spectral lamp Hg)

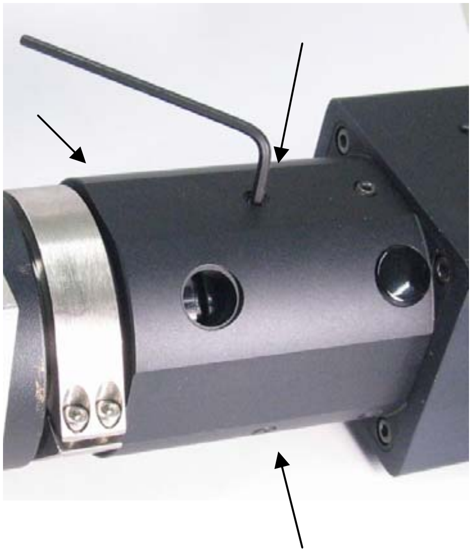
Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

Right BFL.

Spectral peaks are sharp and high intense.

Second indication of wrong BFL is that the front objective is not able to make a good focus either to infinity or to the closest distance marked to the objective (or specified by the objective manufacturer). However, this is not always a problem related to the spectrograph but could also be a faulty objective. Therefore this method is not as reliable as the first one.

## BFL adjustment procedure with *Imspector* Enhanced model



Loose the hex locking screws (3 pcs) from positions shown in image. Note: one screw not seen in this photo. It is situated symmetrically 120° from the other two.

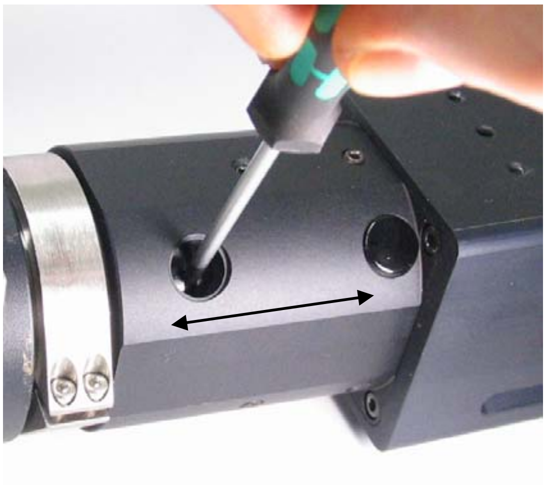
Tool required:

- M2.0 hex screwdriver

Position the spectrograph in front of the spectral source (or integrating sphere illuminated using spectral lamp).

Fill the whole numerical aperture.

Lamp shown in the image is Osram Dulux Mobile.



Spectrograph should be in horizontal position for adjustment.

Adjust the spectral peaks to their narrowest width / highest intensity value. Use a narrow tool to move the focusing lens back or forth from the focusing groove.

After adjustment tighten locking screws carefully.

Note. Standard series models have simple BFL-tool integrated, you need only a screwdriver to adjust BFL.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

# Calibration

Application requirements define what calibrations are needed in the system before proper measurements are achieved. The calibrations may include:

- Spectral axis calibration determines the exact wavelength range that the system covers,
- offset compensation either as a basic dark current subtraction or as a more complete compensation,
- responsivity calibration,
- radiometric calibration,
- spatial axis calibration, and
- application calibration.

## Spectral axis calibration

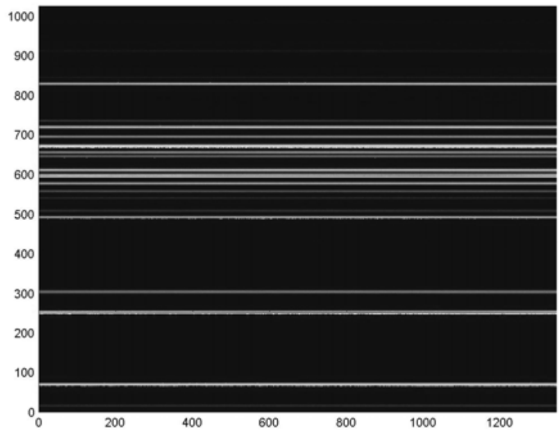
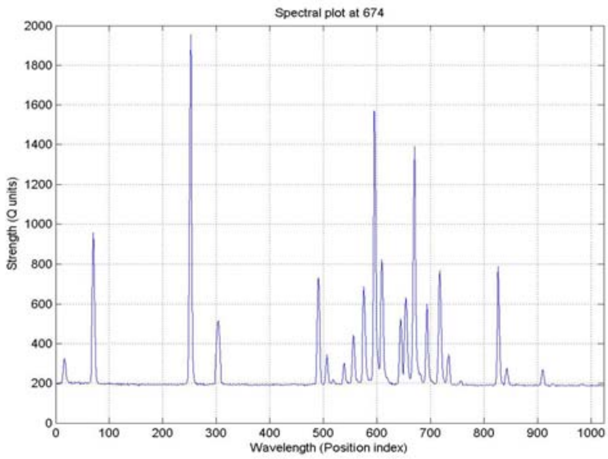
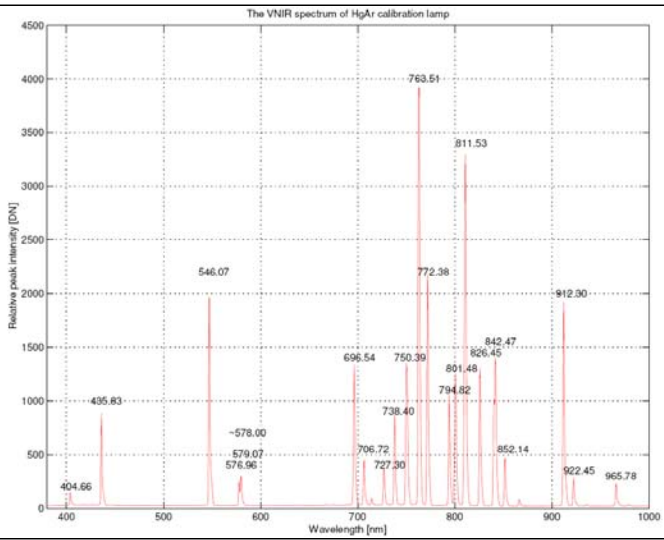
Spectral axis calibration defines the wavelength axis at the detector surface. It is done with spectrally well known light sources. There are several good spectral calibrations sources available both for VIS and NIR spectral range:

- Neon lamp, several good peaks between 585.3 to 1206.6 nm some of which, however, are difficult to use due to overlapping. Neon lamps are used in commercial applications as signalling lamps, so these are widely available and very cheap.
- Fluorescent lamps are cheap (like Osram Dulux Mobil handheld lamp) and provide quick way to check the calibration from time to time. All common fluorescence lamps have easily resolvable peaks at 404.7, 435.1 and 546.1 nm. This lamp can also be used above 1000 nm for the calibration of *ImSpector* N17 versions. The clear lines are: 1014, 1129, 1357, 1395 and 1530 nm.
- HeNe -laser, wavelength 632.8 nm, very stable and high intensity versions available, may need a beam expander to fill the whole input slit. NOTE: lasers could also be used with an integrating sphere to fill the whole input slit and NA of the spectrograph.
- Diode lasers, several wavelengths from 630 to 950 nm, stability is questionable due to small changes in intensity and centre wavelength caused by temperature or drive current variations. Wavelength should be checked from time to time.
- Xenon lamp, some peaks from 418.0 to 992.3 nm, outputs also a continuous spectrum that can be a nuisance.
- Mercury lamp, good peaks in visible region from 404.7 to 615.0 nm, may have some low level continuous spectrum also.
- Mercury-Xenon lamp, characteristics are as Xenon and Mercury lamps combined.
- Interference bandpass filters, these can be obtained to any part of the VIS or NIR spectrum, can be used with ordinary halogen or tungsten lamps. Temperature and filter angle variations should be taking into account.

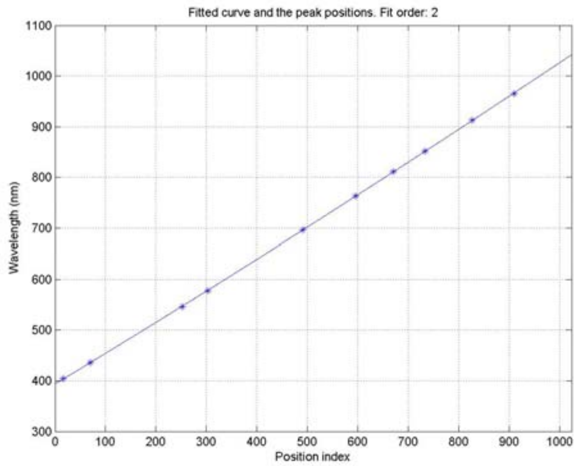
Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

While calibrating the spectral axis also the effect of discrete sampling of the CCD element should be taken into account. In practice it is quite difficult to separate CCD's effect.

## Spectral Calibration Procedure

| | |
|---|---|
|  | This is a image with spectral light source captured with spectral lamp HgAr and Imspector V10E. There are 1024 spectral pixels and 1344 spatial pixels. |
|  | Here is the spectral profile of image above. |
|  | We need reference wavelengths of HgAr lamp for calibration. In most cases you need at least 5 known wavelengths across the wavelength range for proper calibration.<br><br>In this case we have plenty of known spectral peaks in range. |

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

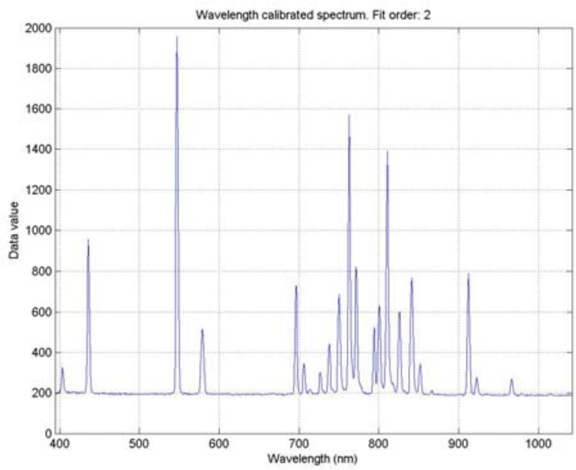



Then you have to fit a curve along data points in wavelength/spectral pixel chart.

In this case equation for fitted curve is

$$WL = 0.0000315\,X^2 + 0.60103X + 393.77 \text{ (nm)}$$

X is spectral pixel position,
WL is wavelength




Wavelength calibrated spectrum plot.

| Spectral pixel | Wavelength (nm) | Pixel width (nm) |
|---|---|---|
| 1 | 394.37 | 0.60 |
| 2 | 394.97 | 0.60 |
| 3 | 395.57 | 0.60 |
| 4 | 396.17 | 0.60 |
| 5 | 396.78 | 0.60 |
| . | . | . |
| . | . | . |

Table. Example of the wavelength calibration table for application use.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

# Spatial axis calibration

Spatial axis calibration defines the position of the imaged scene line pixels on the detector surface. If it is not possible to deduce it from the pattern on the target surface, a special test target can be used on the real target, see 'Offset compensation'.

Spatial axis calibration is also needed when multipoint fibre optics is used in the spectrograph input. The position of each fiber in the spatial axis of the detector is marked in order to create a look-up table for readout and integration of the data channel by channel.

## Field of view and focus

The ImSpector with an area (frame) camera is basically a "line scan" system, i.e., the spectral measurement is done across a line at the target surface at a time. The purpose of the ImSpector spectrograph alignment with respect the target is to ensure that :

- the measurement line is across the desired position on the target surface,
- light source illuminates exactly the right place and is evenly distributed, and,
- lens focus is exactly on the sample surface.

These goals can be achieved by using a test target and the adjustment procedure described here. The target is placed on the measurement surface for alignment and removed after that.

The ImSpector produces spectral image where line pixels are in one dimension and spectral pixels in the other dimension. Thus, when colored objects are observed, it may be difficult to interpret the location of the line on the target due to both spatial and spectral variation in the image. Hence the best result is achieved by using a black and white test target, black being "black" throughout the whole spectral region and white giving signal at all wavelengths. The test pattern can be easily produced, enlarged, reduced etc. using a copy machine.

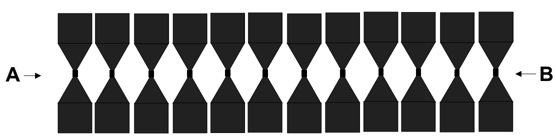



Figure. Basic test target for alignment. The line A-B is the desired measurement line.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

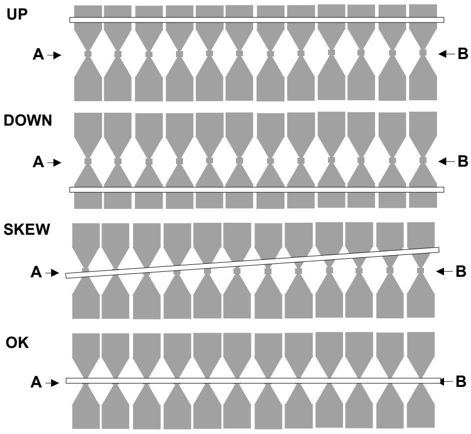



Figure. Possible errors and proper alignment.

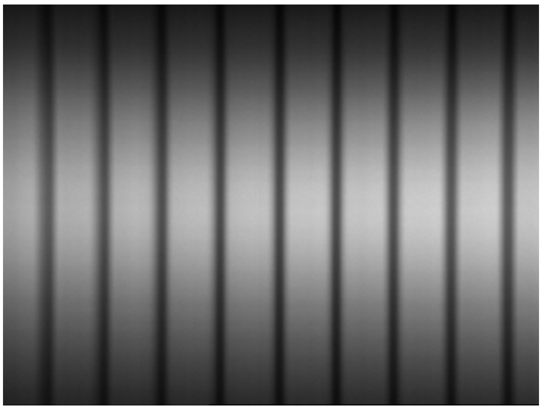
## Focusing and alignment procedure

Following the ImSpector user manual, check that the ImSpector is properly aligned to camera.

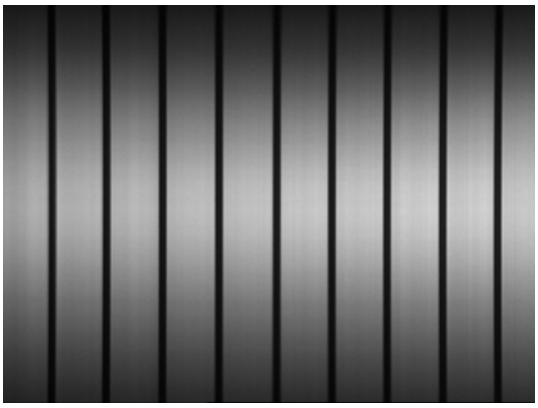
The test target is placed on the object surface so that the line A-B corresponds to the desired measurement line.

First the light source should be visually aligned to give maximum intensity across the line A-B. The alignment is particularly important if a narrow fiber optic line light source is used.

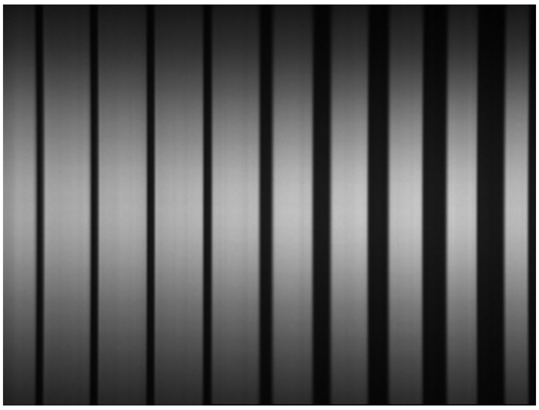
Alignment of the position of the spectrograph/camera unit is easiest when live image from the camera is available.

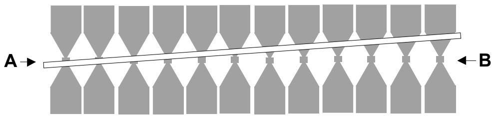


Out of focus

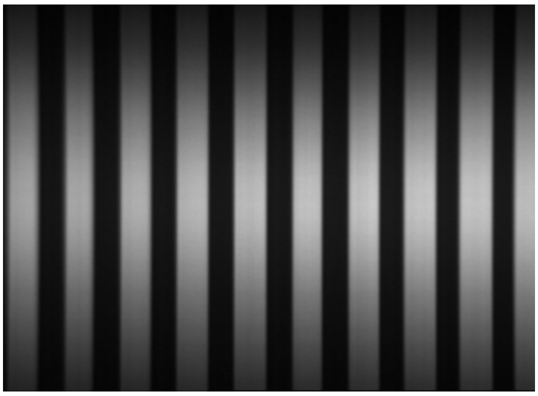


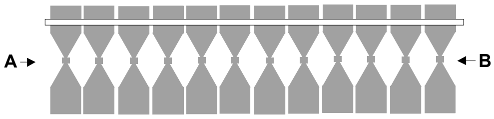
Focus ok






The spectrograph looks above or under the line A-B ⇒ move the spectrograph/camera unit up or down so that the width of the black columns in the image becomes to its minimum.






The spectrograph looks above or under the line A-B ⇒ move the spectrograph/camera unit up or down so that the width of the black columns in the image becomes to its minimum.

# Offset compensation

## Offset created by dark current

CCD detector generates charges even though there is no light exposure on the detector. These temperature generated charges cause small signal which is called dark current and which typically varies from pixel to pixel. In precise measurements this offset has to be measured by blocking the light path to the spectrograph and storing the dark frame and subtracting it (pixel by pixel) from all further measurements. The amount of dark current depends on integration time so if integration time is changed also a new dark image should be measured.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

Dark current offset depends on temperature and integration time. Therefore, best result is achieved with a temperature stabilised detector. Another way to compensate for the dark current temperature drift is, with detectors having masked dark pixels, to use the signal from these pixels to provide an average correction for all other pixels.

### More complete offset compensation

There are usually also other small sources creating an offset in the image than the dark current. They are CCD frame shift smear and optical stray light. The offset due to these effects corresponds to the overall amount of light coming into the system. This correction is essential particularly in applications requiring absolute spectral information, like in absolute color measurement.

## Responsivity calibration

The detector responsivity to light varies from pixel to pixel and the response is also wavelength dependent. Also the throughput of lens and spectrograph depends on wavelength. These variations can be calibrated by measuring a white surface, storing this image and taking then the ratio of any sample image to this white image (after dark current subtractions). This procedure in fact produces the reflectance of the sample/target.

Light source color temperature drift and lighting spatial non-uniformity are also compensated for.

## Radiometric calibration

This is needed only when the absolute spectral radiance ($W/m^2$ nm sr) of the target is to be measured. Radiometric calibration is done with a calibrated radiance standard, which typically consists a halogen lamp attached to an integrating sphere.

## Application calibration

Application calibration means teaching the system to recognize certain spectral features of the target and produce information about the specified target property to which the spectral features correlate. The property can be color or some other physical parameter or concentration of a chemical constituent. Teaching is done with a representative set of known (characterized) samples that provide the basic set of spectrum library.

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

# ImSpector Specifications

## *ImSpector* Standard Series Specifications

| **ImSpector Standard** | **V8** | **V10** |
|---|---|---|
| **Optical characteristics** | | |
| Spectral range | 380 - 780 nm<br>±10 nm | 400 - 1000 nm<br>±10 nm |
| Dispersion □ | 60.6 nm/mm | 90.9 nm/mm |
| Spectral resolution<br>(with 80 µm slit) | 6 nm | 9 nm |
| Image size | 6.6 (spectral) x 8.8 (spatial) mm, corresponding to standard 2/3" image sensor.<br>V8 is also available with 4.8 (spectral) x 6.4 (spatial) mm image size, corresponding to standard 1/2" image sensor. | |
| Spatial resolution | 15 line-pairs/mm, rms spot radius <40 µm within 1/2 " image area<br>rms spot radius <60µm within 2/3 " image area | |
| Aberrations | Insignificant astigmatism | |
| | Bending of spectral lines across spatial axis (smile) <50 µm (1/2 " area), <80 µm (2/3 " area)<br>Bending of spatial lines across spectral axis (keystone) <16 µm (1/2 " area), <25 µm (2/3 " area) | |
| Numerical aperture | F/2.8 | |
| Slit width | 13, 25, 50, 80, 150 □m readily available | |
| Effective slit length | 9.8 mm | |
| Total efficiency (typical) | > 50%, independent of polarization | |
| Stray light | <0.5 % (halogen lamp, 633 nm notch filter) | |
| **Mechanical characteristics** | | |
| Size, cased | (L) 135 x (W) 70 x (H) 60 mm | |
| Size, OEM | (D) 35 x (L) 139 mm | |
| Body, cased | Anodized aluminum with thread for standard camera tripod and M4 | |
| Body, OEM | Anodized aluminum tube | |
| Lens and camera mount | Standard C-mount adapter | |
| User adjustments | Image axis relative to detector rows | |
| | Back focal length adjustable ±1mm | |
| **Environmental characteristics** | | |
| Storage | -20 … +85 °C | |
| Operating | +5 … +40 °C, non-condensing | |
| **NOTES** | | |
| | Dispersion and resolution are given for 2/3 " image size, for 1/2 " image size the dispersion is 27% lower. | |
| | System spectral and spatial resolutions also depend on the discrete imaging nature of detector and lens quality. | |
| | Order blocking filter is available for mounting on the detector window. | |

Spectral Imaging Ltd.
POB 110
Teknologiantie 18 A
FIN-90571 Oulu, Finland
Tel. +358 (0)10 4244 400
Fax +358 (0)8 388 580
Email info@specim.fi
www.specim.fi

ENHANCE YOUR PERCEPTION

## *ImSpector* Enhanced Series Specifications

| ImSpector | V8E | V10E | N17E | N25E |
|---|---|---|---|---|
| **Optical characteristics** | | | | |
| Spectral range | 380 - 780 nm<br>±10 nm | 400 - 1000 nm<br>±10 nm | 900 - 1700 nm<br>±10 nm | 1000 - 2500 nm<br>± 10 nm |
| Dispersion | 65 nm/mm | 97.5 nm/mm | 110 nm/mm | 208 nm/mm |
| Spectral resolution<br>(with 30 µm slit) | 2 nm | 2.8 nm | 5 nm | 8 nm |
| Image size | max. 7.15 (spectral) x 14.3 (spatial) or<br>max. 16 mm diagonally | | max. 7.7 (spectral) x 12.8 (spatial) mm | |
| Spatial resolution | rms spot radius <9 µm | | rms spot radius <15 µm | |
| Aberrations | No astigmatism | | No astigmatism | |
| | Bending of spectral lines across spatial axis (smile) <5µm<br>Bending of spatial lines across spectral axis (keystone) <5µm | | Smile <10µm<br>Keystone <8µm | |
| Numerical aperture | F/2.4 | | F/2.0 | |
| Slit width | 18 and 30 µm readily available, others on request | | | |
| Input optics | Telecentric | | | |
| Effective slit length | 14.3 mm | | | |
| Total efficiency (typical) | > 50%, independent of polarization | | | |
| **Mechanical characteristics** | | | | |
| Size (OEM) | (D) 55 x (L) 175 mm | | (D) 65 x (L) 200 mm | |
| Body (OEM) | Anodized aluminum tube | | | |
| Lens mount | Standard C-mount adapter | | | |
| Camera mount | Standard C-mount adapter | | Standard U- or C-mount adapter | |
| User adjustments | Image axis relative to detector rows | | | |
| | Back focal length adjustable ±1mm | | | |
| **Environmental characteristics** | | | | |
| Storage | -20 … +85 °C | | | |
| Operating | +5 … +40 °C, non-condensing | | | |
| **NOTES** | | | | |
| | System spectral and spatial resolutions also depend on the discrete imaging nature of detector and lens quality. | | | |
| | Order blocking filter is available for mounting on the detector window. | | | |