HYPERSPECTRAL NIR CAMERA

Technical Note, ver. 1.2

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1 Hyperspectral Camera

1.1 Introduction

This report introduces the Hyperspectral Camera system from Headwall Photonics and describes it in terms of function, performance and potential limitations. From the point of delivery the camera has been subjected to extensive high level testing to evaluate and identify potential performance issue. In addition to presenting the results from the test a standard operation procedure is also given in details.

Throughout the analysis the following nomenclature is used

x : Scalar
$\mathbf{x}$: Column vector
$\mathbf{x}_{i,n}$: The n'th datasample at subcoordinate i.
$\mathbf{X}$: Matrix
$\mathcal{X}$: 3-way tensor

It should be noted that the light source used to acquire all the hyperspectral images are temporary and not the intended. As all images are compensated for the light source characteristics we do not expect this to have any impact on the evaluation of the camera or any conclusions.

In section 1.2 the camera system is introduced followed by a detailed performance evaluation of the camera in section 1.3. A standard procedure of how to operate the camera describing the steps in detail can be found in section 1.4.

1.2 The Camera System

The hyperspectral camera itself is manufactured by the Belgium company XenICs, which also produces the NIR InGaAs sensor used. It is a line-scan camera sensitive from appr. 900-1700nm. meaning it can not acquire an entire image at once. In this camera the vertical axis of the sensor is being reserved for the projected wavelengths and thus only one line can be scanned at the time.

The camera and the setup is shown in Figure 1.1. A dedicated NIR light source illuminates the sample uniformly along the scan line and an advanced optic system developed by Headwall Photonics disperses the NIR light onto the camera sensor for acquisition. This is described in further details in section 1.2.1. A sledge developed by MICOS GmbH moves the sample passed the viewslot of the camera allowing it to acquire a hyperspectral image. This is achieved using a thread driven sledge ensuring high precision movements.

In addition a set of software tools from all manufactures are included to control, calibrate and use the camera system, described below.

- X-control (*XenICs*). Basic camera software to acquire line scans and to calibrate and tune the camera parameters.
- Moco demo (*MICOS GmbH*). Simple software to control the sledge movement.
- Hyperspec Software (*Headwall Photonics*). Image acquisition software based on `LabView` controlling the sledge and line-scan camera to capture images.

The camera system software and hardware includes a series of automated processing steps for the image acquisition, e.g. dead pixel removal, light compensation etc.. In the final set up of the system these automated steps are avoided in order to have maximum control of the entire image processing pipeline. This means additional test must be conducted and a series of `Matlab` function are developed to replace these steps.

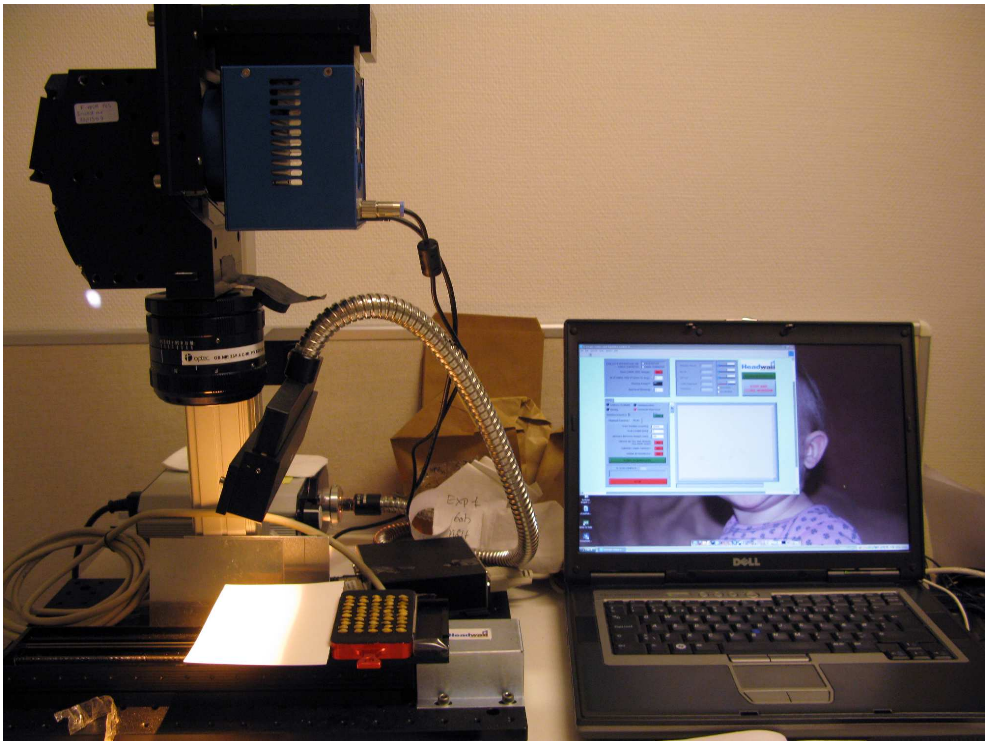

Figure 1.1: Mechanical setup of the hyperspectral camera system. (*source: Headwall Photonics Inc.*).

1.2.1 Light Dispersion

In order to separate the different wavelengths an optical system based on the Offner principle is used as illustrated in figure 1.2. It consists of a set of mirrors and gratings to guide and distribute the incoming light into a range of wavelengths, which are projected onto the InGaAs sensor.

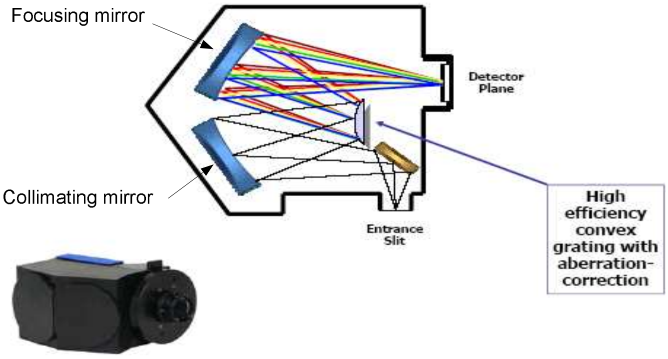

Figure 1.2: The Offner principle used to disperse the NIR light and project it onto the InGaAs sensor. (*source: Headwall Photonics Inc.*).

The sensor has a resolution of 320 spatial pixels and 256 spectral pixel, i.e. a physical resolution of 320×256 pixels. Due to the Offner dispersion principle (the convex grating) not all the light are in focus over the entire dispersed range. This means if the light would be dispersed over the whole 256 pixel wide sensor the wavelengths at the periphery would be out of focus. In order to avoid this the light is only projected onto 166 pixels instead and the top 90 pixels are disregarded. This means it essentially becomes a trade-off between spatial sampling resolution and the focus quality of the image.

1.3 Camera System Performance

In this section the camera system is subjected to a series of test in order to evaluate the performance in terms of image quality. This analysis forms the basis for the operational procedure described in section 1.4.

1.3.1 Camera Calibration

A vital part of the camera system is the possibility to tune or calibrate the camera itself. A small set of parameters regarding the actual acquisition or sampling of the sensor pixels can be adjusted. This allows the user to tune the camera for optimal performance depending on the sample, light conditions, lens, distance to object etc. This however also means the following performance evaluation of the camera is highly dependent on the calibration set used. Prior to any image acquisition for the performance test the camera has been calibrated using the procedure described in section 1.4.3.

1.3.2 Sensitivity

The InGaAs sensor is specified to have a sensitivity range of appr. $900 - 1700$nm. Unfortunately this specification is not based on a lower ±3db level limit (as for e.g. loudspeakers). Instead the smallest detectable highest and lowest wavelengths are used to designate the active range, as shown in Figure 1.3.

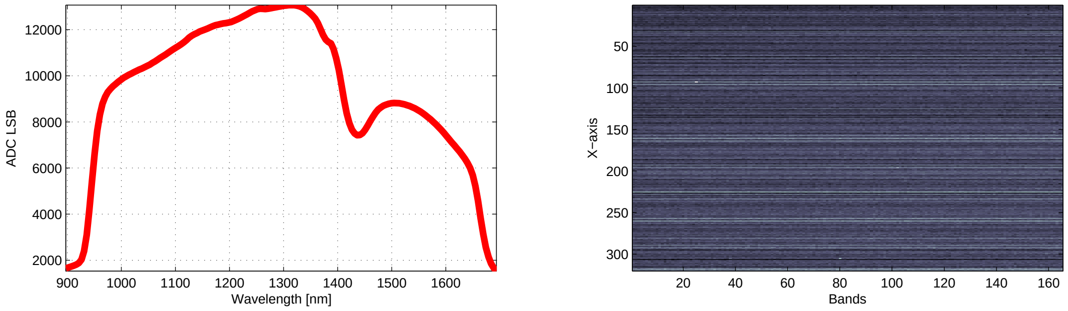

Figure 1.3: Average spectra for white reference (NCS-0300) and dark background current image.

The left illustration shows how the sensitivity of the sensor in the periphery is extremely low and with corresponding low Signal-to-Noise ratio (SnR). This is particularly evident from the $900 - 950$nm range, where almost no light can be detected and the sensor has very poor response. This means the wavelength ranges $900-950$nm and $1650-1700$nm will typically be removed in a pre-processing step and excluded in the further analysis in order to avoid these high absorbances to dominate any signal processing analysis as outliers. The corresponding dark current image shown right in Figure 1.3 clearly reveals the horizontal lines present on the sensor.

1.3.3 Dispersion Higher Order Components

In a optical system used in the camera system the incoming NIR light is divided into infinitely many subcomponents denoted by their order as also illustrated in Figure 1.5. The sensor of the camera is then placed and fixed to capture the 1st order component. The dispersion components are however not discrete and will overlap. This means higher order attenuated component are also projected onto the sensor leading to spurious wavelength components.

In order to evaluate the influence of these higher order components and thus the robustness of the system a band blocking filter has been inserted in front of the lens blocking most of the NIR light (the filter characteristics shown in Figure 1.4).

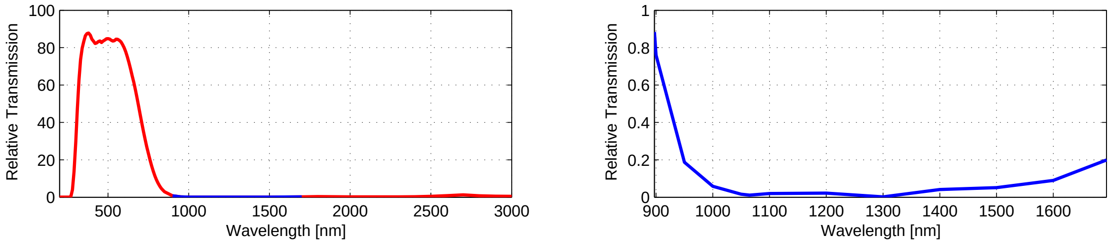

Figure 1.4: Transfer function of bandblock filter (zoomed in right figure).

Acquiring a white reference hyperspectral (NCS-0300) with a subsequent dark current correction the average spectra is shown in figure 1.6.

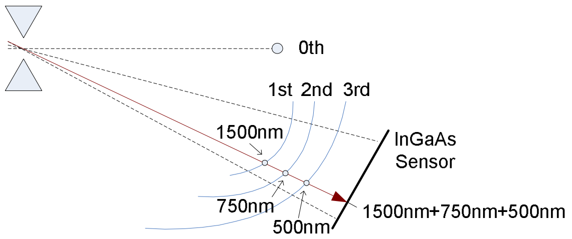

Figure 1.5: Principle of dispersion showing sampling of higher order components.

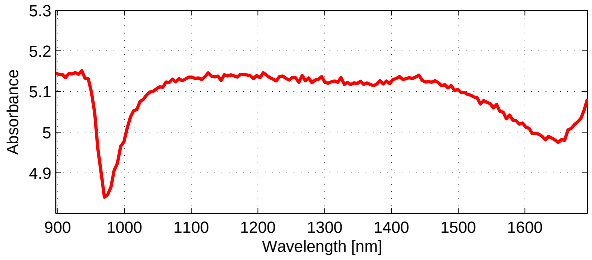

Figure 1.6: Camera response to bandblock filter (dark current corrected).

The spectra clearly shows how almost no higher order components has been captured and proves how the system is very robust towards higher order dispersion components. This further omits the need to include a set of filters to remove such higher order components in the system.

1.3.4 Noise levels

The sampling resolution of the camera is 14bits defined by the Analog-to-Digital Converters (ADC), i.e. the camera output are integer values ranging from $0 - (2^{14} - 1)$. As always in real world application the sensor of the camera generates background noise, which may decrease the effective amount of bit to represent the pixel intensity.

The background noise generated is caused by the sensor and the sampling system (pre-amplifiers, ADC's etc.). A common approach to reduce the sensor noise is to cool the sensor prior to image acquisition. The camera is capable of cooling the sensor gradually to lower then $260°\mathrm{K}$ ($-13°\mathrm{C}$) within less than a minute.

The noise level of the sensor can be estimated from a dark current hyperspectral image $\mathcal{X}_{dark} = \{x_{ijk}\}_{ijk=1}^{IJK}$ acquired by obstructing the incoming light to the lens ensuring complete darkness. The average pixel noise σ_{noise} is then estimated by

$$\sigma_{noise} = \sqrt{\sum_{ijk}(x_{ijk} - \mu_{ij})^2} \quad \Rightarrow \quad \sigma_{noise} = 11.4\mathrm{lsb} \quad \vee \quad \sigma_{\mathrm{noise}} = \log_2(11.4\mathrm{lsb}) = 3.51\mathrm{bits}, \tag{1.1}$$

where μ_{ij} denote the index i, j of the average sensor frame, i.e. the average value for each pixel is subtracted and the standard deviation is estimated as the noise level. This shows the background noise contaminates the lower 3.51bits. Based on the noise level the corresponding Signal-to-Noise Ratio (SnR) can be estimated as

$$\mathrm{SnR} = \Big(1.763 + 6.02 \cdot (14 - \log_2(\sigma_{\mathrm{noise}})\Big) \quad \Rightarrow \quad \mathrm{SnR} = 64.9\mathrm{dB} \tag{1.2}$$

Deactivating the cooling and letting the sensor stabilize above the room temperature to appr. $305°\mathrm{K}$ ($32°\mathrm{C}$) and re-estimating the noise levels increases the noise level slightly to appr. 12.6 LSB decreasing the SnR to 64.1dB. Hence the cooling should be active for all image acquisitions.

The noise figures estimated are highly dependent on the calibration set used by the camera. A more attractive calibration set can easily be used to reduce the noise even further, but at the expense of failing to capture the dark current. This will leave dark current artefacts in the corrected image and thus reducing the image quality. In addition the calibration is usually set a bit below the max. value in order to avoid saturation leading to a slight noise increase.

1.3.5 Oversampling

As part of the camera acquisition parameters the step length or distance between line scans Δm can be specified. Normally it is preferred to have square pixels, i.e. same length and width and hence this step length should be specified to obey this (refer to section 1.3.7). In terms of improving the SnR several line scans can be averaged to one by reducing the step length equivalently at the cost of longer acquisition time, e.g. setting $\Delta m \leftarrow \frac{1}{5}\Delta m$ improves the SnR with a factor of 5 however with the cost of 5 times the sampling time.

1.3.6 Illuminator

A dedicated light source box is part in the camera system to illuminate the sample in the NIR range from 900-1700nm. The illumination system has an associated fiber optic cable and line diffusor ensuring an almost uniform light distribution over the sample. The transfer function of the fiber optic cable and associated line diffusor can be measured by evaluating the difference spectrum between the fiber optical cable being used and bypassed, i.e. direct light source.

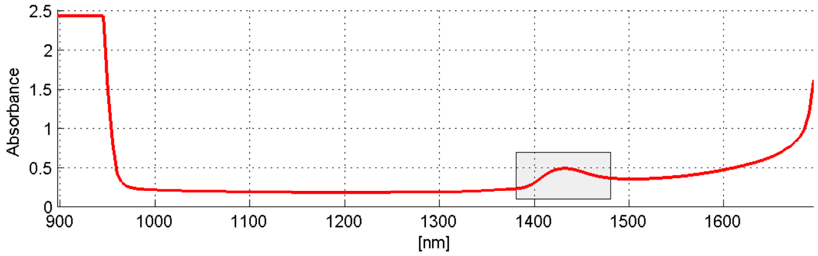

Figure 1.7: Optical fiber characteristics.

From figure 1.7 it is clear to see how the absorbance transfer function increases slightly at around 1425nm due to the fiber optic cable. In addition the low sensitivity of the InGaAs sensor at 900-950nm is also very clear to identify.

In such a camera system it is important that the light source is stable during acquisition. If the light source is unstable or drifts over short time then the subsequent reference compensation might induce fake reflections. It is therefore important to measure the reference reflecting image as part of every image acquisition session.

The light on the sample can be unstable for several reasons. Initially the background light from the room or sunlight can interfere directly. In our case the camera is located in a basement room with no windows and are thus not subjected to sunlight. In order to evaluate the influence from the background room light figure 1.8 illustrates the different spectra of a white reflecting surface (NCS-0300) with and without the room lights on.

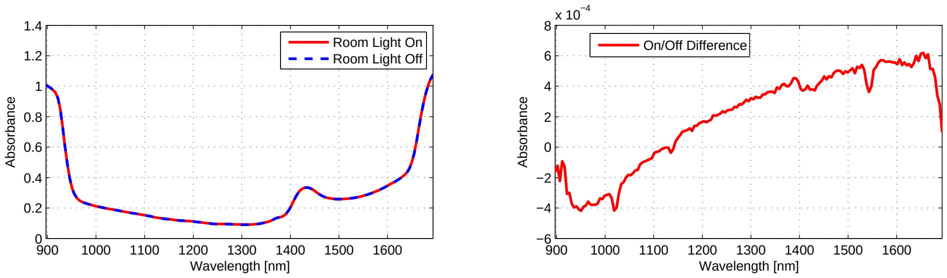

Figure 1.8: Absorbance of a white reflecting surface with and without room lights on.

The figure clearly shows how the room light fortunately has negligible influence on the measurements. This means the room light can be left on without degrading image quality.

Secondly the power supply for the light bulb can have poor performance in terms of stability and noise. Any variation here will affect the light emission of the bulb and also the sample illumination. Finally the light bulb itself can drift over time and eventually burn out for replacement. This again emphasizes why a a reference measurement is preferred as part of any real sample acquisition.

1.3.7 Acquisition Parameters

As a parameter for the line scan camera setup the distance between line scans must be specified. This parameter Δm is dependent on different variables such as the width of the slit ΔS, the distance to the object ΔO and the focal length FL and can be expressed by

$$\Delta m = \Delta S(\frac{\Delta O}{FL} - 1) \tag{1.3}$$

In our setup the following parameters were used: $\Delta S = 25\mu m$, $\Delta O = 250mm$ and $FL = 25mm$. Hence the distance between line scans must be $\Delta m = 225\mu m$. As both the focal length FL and slit width ΔS are constant the distance between line scans is only dependent on the distance to object parameter and this linear dependency can be illustrated in figure 1.9.

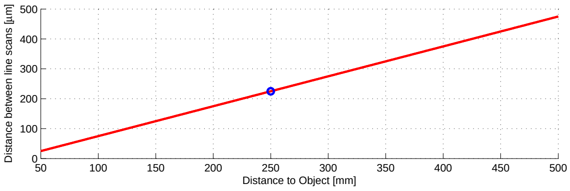

Figure 1.9: The distance between line scans depending on the distance to the object.

1.3.8 Sensitivity to environment

The different parts of the camera system can fade in their performance over time, temperature or the environment in general. Initially the stability of the light source is vital during image acquisition. If the light source should render unstable due to the bulb itself or the associated power supply, then any image acquired will suffer from undesired artefacts. The light bulb may in addition require a short time to stabilize before image acquisition and may also fade over a longer period of time before replacement. The cooling of the sensor also requires a short time to stabilize. This is however measured live by the acquisition program and can be monitored easily. In order to limit the influence from external variables the camera system must be allowed to stabilize prior image acquisition.

It is therefore important to conduct a acquisition procedure, where the sensitivity towards these external factors are minimized. The best approach is simply to acquire white reference and dark current as often as possible to capture any drift.

1.3.9 Dark and Bright reference images

In order to extract the actual NIR response of the samples the influence from both the reference image $\mathbf{X}_{ref}$ and dark current image $\mathbf{X}_{dark}$ are removed. The `Hyperspec` camera software has built-in functionality for this compensation, but in order to have transparency in the entire processing pipeline this step is conducted in `Matlab`.

This means real hyperspectral images for both the reference and dark current images are acquired and the average image frame corresponding to the camera image sensor is used. This also ensures different light illuminations across the line scan will be compensated. Using these two hyperspectral images a single compensated line scan image can be calculated from the measured image $\mathbf{X}_{meas}$ by

$$\mathbf{X}_{ijk}^{(comp)} = \frac{\mathbf{X}_{ijk}^{(meas)} - \mathbf{X}_{jk}^{(dark)}}{\mathbf{X}_{jk}^{(ref)} - \mathbf{X}_{jk}^{(dark)}} \qquad \forall\ i \tag{1.4}$$

where i, j, k denote the indices of the hyperspectral data cube. The dedicated `Matlab` function `prepareCube` can perform the compensation when provided with the hyperspectral reference and dark current images. In order to illustrate figure 1.10 shows typical average reference and dark current line scan image frames.

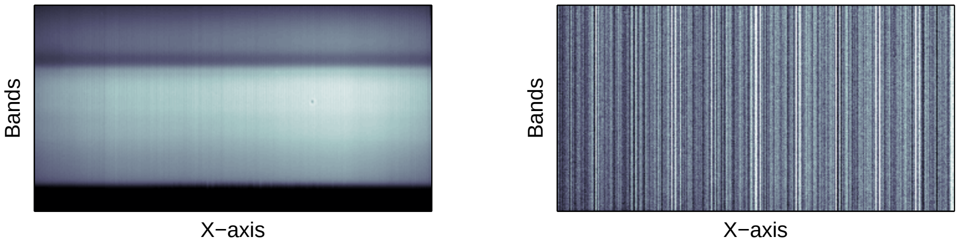

Figure 1.10: The average line scan image of a white reflecting surface (*left*) and the dark current image (*right*).

In order to ensure invariance to drift of the illuminator system it is encouraged to capture a white reference for each acquisition and a dark current image for every 5th acquisition as described in the SoP in section 1.4.

1.3.10 Spectral Performance

The spectral resolution of the camera is solely determined by the mechanical quality of the optical system. In order to verify the spectral performance a set of simple test can be conducted as described below.

Spectral Bandwidth

The spectral bandwidth of the camera is determined by the optical dispersion system and can be estimated from the SRM1920a wavelength standard. By evaluating the 2nd order derivative of the SRM1920a spectrum the bandwidth is determined as the distance between two peaks representing a narrow peak in the original spectrum. This means the peak used must be as narrow as possible in order not to mask the camera's bandwidth. In our case wavelength $f = 1323$nm is relatively narrow and is used for the bandwidth estimation.

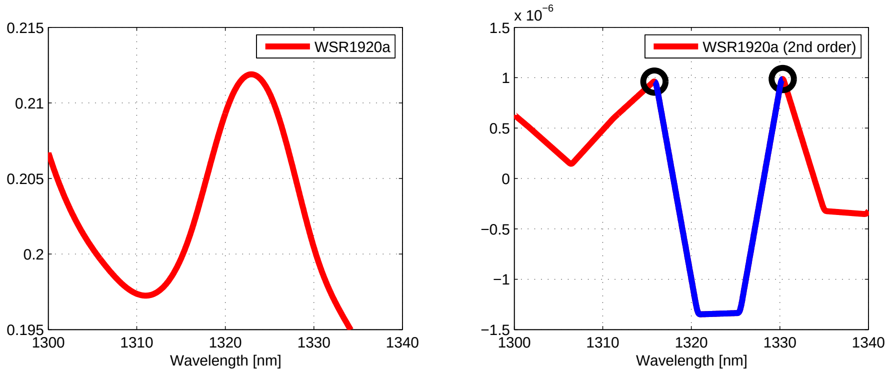

Figure 1.11: The bandwidth of the camera based on the 2nd order derivative of the SRM1920a standard.

Figure 1.11 shows the a zoom of the small peak at $f = 1323$nm and the corresponding 2nd order derivative. From this figure the bandwidth is estimated to $\Delta BW_{meas} = 1330\text{nm} - 1316\text{nm} = 14\text{nm}$. This relatively wide bandwidth is slightly larger than the bandwidth of $\Delta BW_{spec} = 9.5$nm specified by the vendors of the camera system.

In this context the large step between each spectral sample of appr. $\Delta f = 4.8$nm must also be considered. This means the measured bandwidth is quantified by the spectral sampling and thus artificially higher.

SMR1920a Wavelength Standard

Initially the spectral response of the camera can be compared to the SRM1920a wavelength standard [1] to identify any misalignments of the spectral scale. The acquired average spectra of a SRM1920a sample is shown as the red curve in figure 1.12.

In order to adjust the wavelength scale a simple 1st order function is used to recalculate the wavelength scale expressed by

$$wv_i^* = \alpha \cdot i + \beta \tag{1.5}$$

where wv_i^* denote the new wavelength. The function parameters α and β can be estimated using the set of reference points listed in table 1.1 and shown as black circles in the figure.

From these reference points the parameters α and β can easily be found (derivations not shown) and the new adjusted wavelength scale calculated. In figure 1.12 the blue curve depicts the corrected SRM1920a spectra with wavelength differences between appr. $4 - 15$nm.

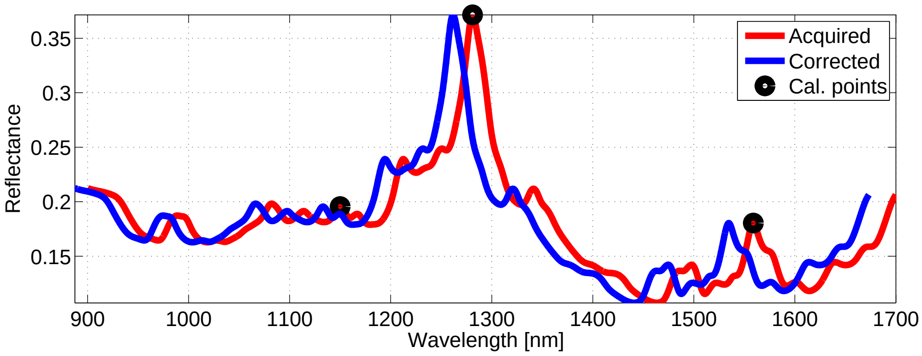

Figure 1.12: The wavelength standard used for calibrating the wavelength scale.

Ref. point	Wavelength
1	$wv = 1132.9\text{nm}$
2	$wv = 1261.8\text{nm}$
3	$wv = 1534.6\text{nm}$

Table 1.1: SRM1920a reference points

The entire calibration functionality is implemented in the `Matlab` function `spectralSRM1920a`, where these reference points are hard coded. The wavelength scale can also be adjusted inside the camera system to ensure a correct wavelength scale being output every time. The approach of post-processing the wavelength scale however ensures an easy and flexible adjustment method.

It is also important to note that this calibration only affect the wavelength scale and not the image data itself, i.e. the quality of the image is not affected if the an image is acquired with a wrong wavelength scale.

Currently three reference points are used as listed in table 1.1. These points are selected based on the bandwidth of the camera system of 10nm according to the SRM1920a standard [1].

1.3.11 Intensity Performance

The linearity of the light intensity scale can be evaluated by measuring a range of gray scale images. For this purpose a gray scale set based on the NCS (Natural Color System[1]) color standard is used ranging from NCS-0300 to NCS-9000, where NCS-0300 denotes the most reflecting surface (brightest white) and NCS-9000 denote the darkest surface (deep black).

The different gray scales are measured one by one and compared to a reference measurement using the FOSS XDS instrument, cf. Figure 1.13. The comparison with the XDS reference measurement can also be used to perform a linear 1st order correction of any acquired image, if desired

1.3.12 Spatial Performance

The camera suffers from a small misalignment in the optical system causing a minor spatial distortion over both the spectral and spatial range. One of the steps in the pre-processing pipeline is hence to correct for these artefacts.

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[1] For a detailed description refer to the NCS website at `http://www.ncscolour.com`

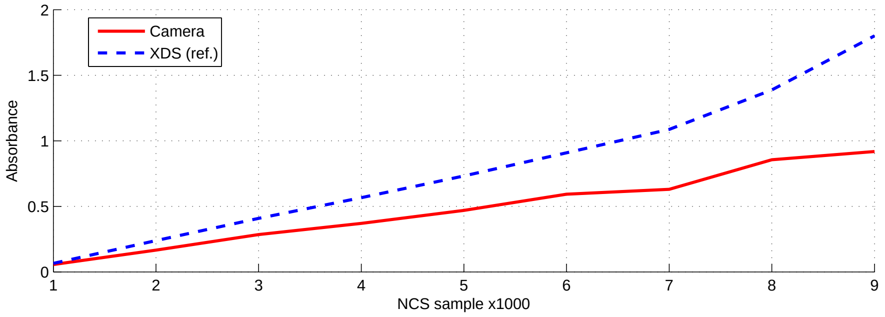

Figure 1.13: The light intensity response to different levels of gray.

The distortion can be captured by acquiring an image of vertical lines and the wavelength standard WSR1920a as shown in Figure 1.14 and 1.15. The acquired lines should ideally be strictly vertical, but the average image reveal a large degree of spectral and spatial distortion increasing toward the lower right corner. Similar distortion can be seen in the WSR1920a image at the bottom of Figure 1.15. The distortion is in the range of $2-3$ pixels and is within the optical systems specifications. The optical system does not allow for any mechanical tuning and the correcting must therefore be applied to acquired images as a pre-processing step.

A new set of corrected coordinates are estimated by aligning the positions of the lines in the vertical line image and horizontal lines at the wavelengths $[1132.9, 1261.8, 1534.6]$nm in the WSR1920a image. The correction is afterwards applied to each band frame by linear interpolation.

Correcting an associated dark current image before or after makes no difference due to the linear operation of the interpolation. Figure 1.16 shows a difference image of an acquired barley kernels image before and after the correction. It is clear to see how the correction has compensated most in the lower right corner, as expected.

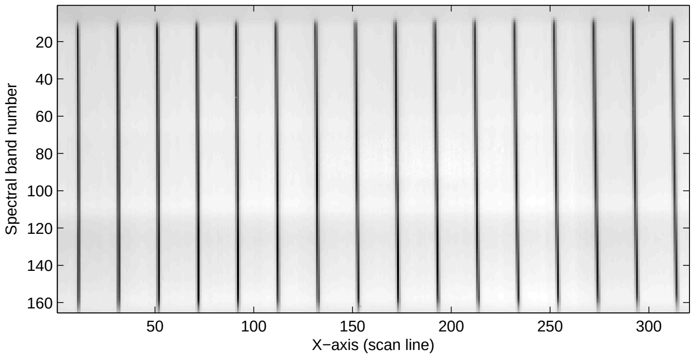

Figure 1.14: Averaged image of the vertical lines used for the calibration showing how the lines become more and more skewed to the right of the image.

1.3.13 Specular Reflections

Specular reflection occurs when a light source can be seen as a direct reflection on the surface of an object, e.g. sun reflection on a glass ball. Pixels suffering from specular reflection are dominated by the light source and may not contain sufficient information of the reflecting material. In our camera system specular reflections typically occur in the middle of the sample, e.g. grain kernels, due to the position of the light source and camera (cf. Figure 1.1).

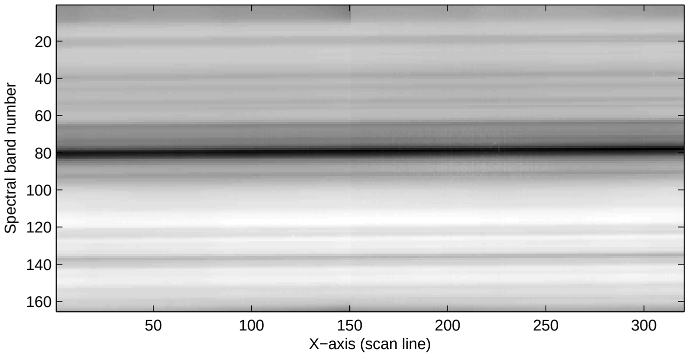

Figure 1.15: Averaged image of the wavelength standard WSR1920a used for the calibration showing how the lines are titling a bit to the left.

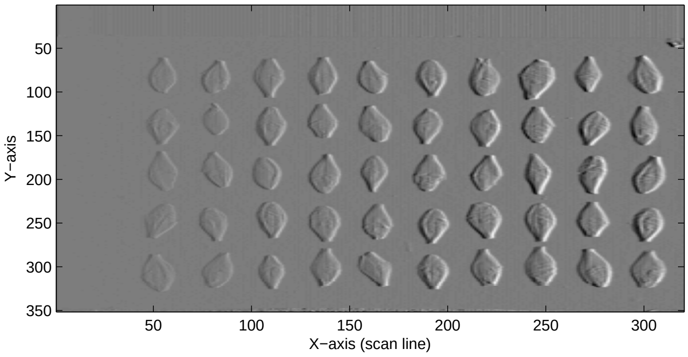

Figure 1.16: Averaged difference image of barley kernels between before and after the image correction.

Since the intensity of a specular reflecting pixel is larger than white reference, due to more direct light path, they are easy to identify and mask out subsequently, cf. Figure 1.17.

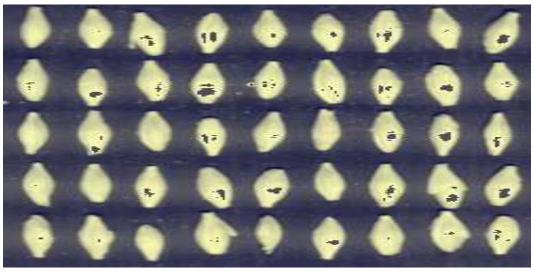

Figure 1.17: Barley kernels, where the specular reflecting pixels identified as dark pixel in the middle of the kernels are removed by mask.

1.3.14 Dead Pixels

During production of the InGaAs sensor it is common for a small set of the resulting pixels to malfunction in terms of response. This means these bad pixels are either stuck to zero or full response (dark or white) and can easily be identified by capturing a white reference or dark current image.

It is unfortunately not possible to re-activate or fix these bad pixels and since they are stuck at the extrema of the light intensity scale they are considered outliers during a subsequent image analysis processing. The only remedy is to exclude them for the dataset or replace them with the average response of its surrounding neighbours. Dust particles on the lens or in optical system might erroneously be identified as dead pixels. In such a case the optical system will have to be cleaned to remove the dust particles.

The camera has fortunately a built-in compensation for dead pixels by replacing them with the average response of its surrounding neighbours. The mask to identify the dead pixels can be estimated using dedicated camera software. By bypassing the mask dead pixels can be identified by analysing the pixel variances, cf. Figure 1.18.

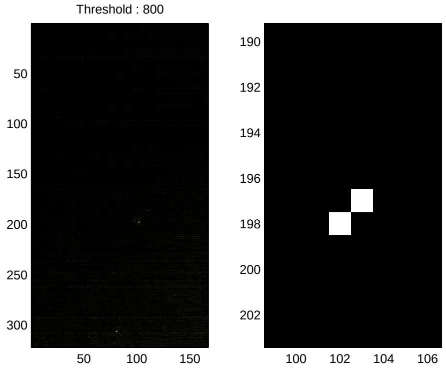

Figure 1.18: Sensor frame image identifying a few dead pixels.

For our camera less than 10 dead pixels are identified corresponding to less than 0.02%. Considering the acceptance limit from the camera manufacturer of 0.9%, this is by far acceptable. Hyperspectral image acquired does not need to be compensated for dead pixels, as this is already conducted by the camera acquisition software. In addition, the identification of specular pixels can further identify any dead white pixels for out masking.

1.3.15 Image Samples

A sample of real-world food samples is shown in Figure 1.19 to illustrate the cameras subjective performance.

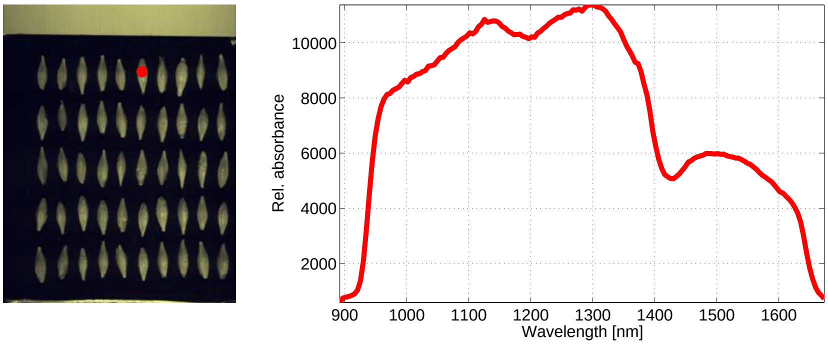

Figure 1.19: Example of acquired raw hyperspectral image of barley kernels and associated spectra prior to any pre-processing.

1.4 Standard Operational Procedure

This section describes how to acquire hyperspectral images using the camera in a step-by-step procedure. The sequence order to acquire an image is listed below.

- Install camera software (*Only needs to be done once.*).
- Setup the camera mechanics (*Only needs to be done once.*).
- Calibrate camera parameters using `x-control` software (*Only needs to be done once.*).
- Spectral Calibration using the SRM1920a standard.
- Spatial Calibration using squared patterns.
- Compensation for reference and dark current images.
- Acquire Hyperspectral Image.

It is assumes during all steps that the camera is turned on along with the moving sledge and NIR light source. The individual steps are described in details in the following sections.

1.4.1 Installing Software

The vendors of the camera and sledge system have their own dedicated software and for the entire system Headwall Photonics has collected additional software components into a single installable program based on `LabView` from National Instruments. To install all software packages use the following procedure.

- Do not connect the camera to the PC yet (this will initiate the search for drivers, which are not installed yet).
- Install XenIC's software by running '*X-Control-Setup-Advanced.exe*'.
- Install MoCo DC software to control the sledge system manually (optional).
- Follow the procedure described in '*CD-1065 Hyperspec A.1.13 Software Manual Rev Y06.pdf*' (installs CD-1079 and CD-1065).
- Go to the '*C:\Program Files\X-Control*' and replace the '*xcamera.dll*' with version 1.2.0.747 (This will fix cooling control of the camera).
- Connect the camera and let Windows install tjhe driver for the camera.
- Start the acquisition software from the '*Hyperspec*' folder in '*C:\Program Files*'.

1.4.2 Mechanical Setup

A standard set up of the camera system is assumed during the operational procedure. Deviations are not prohibited, but may give a different quality of the images.

Initially the position of the camera must be as close to the sample without loosing focus in order to maximized the resolution of the samples. The standard position of camera is to be set to 25cm from lens to object. The camera can be moved by loosening the screws on the side of the vertical bar and adjusting the height of the camera.

Afterwards the focus of the camera lens must be adjusted to the new position. This is achieved by placing a squared paper at the same vertical position as the sample and using the live view in `X-control` software to manually adjust the focus on the lens.

The NIR light source must be turned on during acquisition. Background room light has negligible influence and can be turned on. Sunlight however should be avoided as the influence has not been verified.

1.4.3 Calibration of camera parameters

A large set of parameters can be set to tune the performance of the camera. In order to maximize the quality of the images at the expense of acquisition time, the following standard calibration setup is to be used.

- **Integration time** set to max. of $100000 \mu s$
- **Cooling Temperature** set to $260°$K
- **Fan Cooling** activated
- **Low Gain Mode** activated

The performance of the camera can be additionally tuned by adjusted the sampling range of the Analog-to-Digital Converters in order to minimize the noise level while maximising the dynamic range. Such a calibration is iterative and can be conducted using dedicated the `X-control` software from the camera vendor XenICs.

In the `X-control` software a histogram of the pixels are shown at the bottom and is very useful for tuning the ADC sampling parameters. In calibrating the camera the darkest and brightest image must be acquired to measure the noise floor and saturation level respectively. It is important to capture the noisefloor in order for subsequential removal. In order to tune use the following iterative steps.

- Set the light source to a high level. This can be adjusted down if necessary during the calibration.
- Place a white reflecting surface under the camera, preferably color sample NCS-0300.
- Adjust V_{in} and V_{ref} to ensure no pixels are saturated.
- Obstruct the incoming light by a dark surface, preferably color sample NCS-9000.
- Adjust V_{in} to ensure the noise floor is within the measurement.
- Repeat the steps until the noise floor is captured while avoiding pixel saturation.

The resulting set of parameters can afterwards be saved as a calibration set and subsequently used in the `Hyperspec` software for image acquisition.

A dedicated calibration menu also exist in the `X-control` software, but it is used for identifying dead pixels on the sensor. The camera has the option to store an image identifying these dead pixels and perform automated averaging during acquisition.

1.4.4 Image Acquisition

For the acquisition of a hyperspectral image the `Hyperspec` software is used, all other camera software packages must be shut down. To acquire an image use the following procedure.

- Load the calibration pack.
- Set the '*Distance Between Images*' according to distance to object or oversampling, refer to section 1.3.5 and 1.3.7.
- Deactivate all reference and dark current compensations.
- Place object in sample tray with a NCS-9000 color sample as background or similar.

- The start position of the scanning depends on the position of the sample. This needs to be adjusted by setting the '*Start Position*' and '*Scan Length*' accordingly.
- Activate the '*Create BIL File and Header File from Scan*' to ensure the image is saved.
- Press the '*Start Acquisition*' and enter a filename to save the image to.

The acquired image is now saved and can be viewed by the '*View Image and Spectral Plots*'.

1.4.5 Reference and Dark Current Compensation

Any acquired image must be compensated for the reference and dark current images as described in section 1.3.9. To obtain a set of hyperspectral reference and dark current images use the following procedure.

- Use a white reflecting surface as a sample, preferably color sample NCS-0300.
- Acquire the reference image.
- Use a dark surface to obstruct the incoming light to the camera lens, preferably color sample NCS-9000.
- Acquire the dark current image.

References

[1] Standard reference material 1920a (near infrared reflectance wavelength standard from 740nm to 2000nm). *National Institute of Standards and Technology (NIST)*.