SOC710 & Spectral Radiance Analysis Software User's Manual

SURFACE OPTICS CORPORATION

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SOC710 &
Spectral Radiance Analysis Software
User's Manual

11555 Rancho Bernardo Road
San Diego, CA 92127-1441
Phone: (858) 675-7404
Fax: (858) 675-2028

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Advisories

Three types of advisories are used throughout this manual to provide helpful information or to alert you to the potential for hardware damage or personal injury. They are Notes, Cautions, and Warnings. The following is an example of each type of advisory. Use caution when servicing any electrical component.

NOTE
An amplifying or explanatory comment related to procedural steps or text.

CAUTION
Used to indicate and prevent the following procedure or step from causing damage to the equipment.

WARNING
Used to indicate and prevent the following procedure or step from causing damage to the equipment.

Disclaimer: We have tried to identify all situations that may pose a warning or caution condition in this manual. However, Surface Optics Corporation does not claim to have covered all situations that might require the use of a Caution or Warning.

Safety Instruction

For your own safety and in order to guarantee safe operation of the system please read the following information prior to use.

- Never operate the system in areas where water or dust might penetrate the housing.
- Place the system on a stable base. Shocks, like dropping the system onto the floor, might cause serious damage to the device.
- Always unplug the system before cleaning it. Do not use cleaning liquids or sprays. Use only a dry, soft cloth on the case. Clean the optics with non-scratching lens tissue and lens cleaning fluid. Do not use strong solvents such as acetone.
- Make sure that the connecting cables are in good condition.
- Detach the system and contact the customer service in the following cases:
  - When a cable or plug is damaged or worn-out.
  - When water or other liquids have soaked into the device.
  - When the device is not working properly after following all instructions in the User's Manual.
  - If the system has been dropped or the housing has been damaged.

NOTE
Before handling the SOC710 Hyperspectral Imager, read the following instructions and safety guidelines to prevent damage to the product and to ensure your own personal safety.

Refer to the "Advisories" section for advisory conventions used in this manual, including the distinction between Warnings, Cautions, and Notes.

- Always use caution when handling/operating the instrument. Only qualified, experienced, authorized electronics personnel should access the interior of the instrument. The power supplies produce high voltages and energy hazards, which can cause bodily harm.

- Use extreme caution when installing or removing components. Refer to the installation instructions in this manual for precautions and procedures. If you have any questions, please contact Surface Optics Technical Support.

Never modify or remove the radio frequency interference shielding from your instrument. To do so may cause your installation to produce emissions that could interfere with other electronic equipment in the area of your system.

In addition, take note of these safety guidelines when appropriate:

- When you disconnect a cable, pull on its connector or on its strain-relief loop, not on the cable itself. Some cables have a connector with locking tabs. If you are disconnecting this type of cable, press in on the locking tabs before disconnecting the cable. As you pull connectors apart, keep them evenly aligned to avoid bending any connector pins. Also, before connecting a cable, make sure both connectors are correctly oriented and aligned.

Warranty & Tech Support

Product Warranty

The SOC710 Hyperspectral Imaging System carries a one-year warranty against defects in materials or workmanship from the date of shipment to the original purchaser. Any products found to be defective in material or workmanship will be repaired or replaced promptly.

NOTE
Products that have been modified will not be covered under this warranty.

Warranty & Repair

Please contact Surface Optics regarding warranty repair before returning the product.

NOTE
All returns to Surface Optics for Repair/Replacement/Credit must be shipped back to Surface Optics with shipping charges and duties paid.

Returns for Repair/Replacement/Credit

It is not required, though highly recommended, that you keep the packaging from the original shipment of your Surface Optics product. However, if you return a product to Surface Optics for warranty repair/replacement, you will need to package the product in a manner similar to the manner in which it was received from our plant. Surface Optics cannot be responsible for any physical damage to the product or component pieces of the product that are damaged due to inadequate packing.

Physical damage sustained in such a situation will be repaired at the owner's expense in accordance with **Out of Warranty Procedures**. Please, protect your investment; a bit more padding in a good box will go a long way to ensuring the device is returned to us in the same condition you shipped it in.

Out of Warranty Repair

Repair for out of warranty Surface Optics manufactured products must be discussed with a technician before arrangements for the repair can be made.

Once the product is received at Surface Optics, an evaluation of the product/unit will be performed and a technician will contact you to discuss repairs and to obtain authorization for the repair work to be performed.

Contacting Technical Support

For a quick response, send an email to support@surfaceoptics.com with a detailed description of your problem, or visit our web site at:

http://www.surfaceoptics.com/Support.htm

Our support department can also be reached by fax at (858) 675-2028 or by phone at (858) 675-7404.

Support is available Monday through Friday, 8:00 AM to 5:00 PM PT. When contacting Surface Optics Technical Support, please be sure to include the following information:

1. Name
2. Company Name
3. Phone Number
4. Fax Number
5. E-mail Address
6. Surface Optics Product Name
7. Surface Optics Serial Number
8. Computer Make
9. Computer Model
10. Operating System and Version
11. Description of the Problem.

Returning Merchandise to Surface Optics

If service is required, and arrangements have been made with a Surface Optics representative, please ship the **well-packaged** product to the address below:

Surface Optics Corporation
11555 Rancho Bernardo Road
San Diego, CA 92127-1441
USA

It is not required, though highly recommended, that you keep the packaging from the original shipment of your Surface Optics product. If you return a product to Surface Optics for warranty repair/replacement you will need to package the product in a manner similar to the manner in which it was received from our plant. Surface Optics cannot be responsible for any physical damage to the product or component pieces of the product (such as the host or expansion interfaces for PCI expansion systems) that are damaged due to inadequate packing. Physical damage sustained in such a situation will be repaired at the owner's expense in accordance with Out of Warranty Procedures. Please, protect your investment; a bit more padding in a good box will go a long way to ensuring the device is returned to use in the same condition you shipped it in.

NOTES

1.0 SOC710 Data Acquisition Software

1.1 Introduction and System Requirements

The SOC710 Hyperspectral Imaging System is a precision piece of equipment utilizing a high-speed, low-noise silicon-based CCD, high quality visible-to-near infrared spectrometer, integrated scanning system, and capture and analysis software. The SOC710 can record HS imagery at a rate of 4 megabytes of data every second (128-band elements per second at 12-bit resolution, 520 pixels per row, up to 33 rows per second). The system's spectral response covers the visible and NIR spectral range from 0.4 – 1.0 microns and can be used in normal lighting conditions with variable exposure times and gain. The system can be configured to operate either as an imager or as a line scan camera.

1.1.1 Camera Specifications

- Spectral Band: 0.4 – 1.0 microns
- Number of Bands: 128
- Dynamic Range: 12-bit
- Line Rate: Up to 33 lines/second
- Pixels per line: 520
- Lines per cube (typical): 696
- Exposure Time: 10 -> 10^3 milliseconds

The SOC710 system also includes Surface Optics' *SRAnalysis* post-processing software for data calibration and analysis.

1.1.2 Computer System Requirements

Check the following requirements to see if your system will support the SOC710 Hyperspectral Imaging system:

- USB 2.0 port
- Processor, Pentium Class or Above
- 1024 MB RAM
- Possible Operating Systems:
  - Microsoft Windows XP (32-bit)
  - Microsoft Windows 7 (not yet supported)
  - Linux (not supported)

If you are working with the Linux operating system or Microsoft Windows 7, please contact Surface Optics Corporation's service department or visit our website www.surfaceoptics.com for updated information on our Linux or Microsoft Windows 7 support.

1.2 Getting Started: System Installation

NOTE

The SOC710 Software suite currently runs under the Windows XP™ Operating System.

1.2.1 Installing the System Software and Drivers

Several devices inside the SOC710 are controlled through a single USB connection; (1) focus camera, (2) spectral imaging camera, and (3) the internal scanning mechanism which operates via the USB cable through a 'COM' port on the computer. Before operating the instrument, the appropriate software and drivers must first be installed. The following is a list of the software drivers and the order in which they are installed:

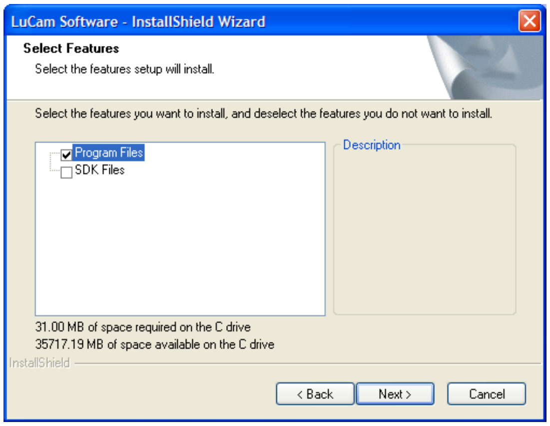
1. SOC710 Operating Software.
2. SOC USB Driver.
3. *Lumenera*™ Camera Drivers (focus and spectral).
4. *SRSAnalysis*™ Data Analysis and Calibration Software.

In addition to the installation of the drivers, the COM port used by the instrument must be set in the software when the instrument is first used.

1.2.2 Installing the System Data Acquisition Software

1. Insert the CD labeled 'SOC710 Installation Software' into the computer and follow the installation instructions.

2. In the event you are asked to load an *unsigned* driver, please answer '*continue anyway*'.



3. **3.** When the Lucam™ Software installer asks what software is to be loaded, select only the program files. The installation of the SDK files requires a password which is not provided.

<u>1.2.3 Connecting the System to a Computer</u>

Once the installation of the drivers and software has been completed, the camera must be plugged in to determine the COM port for the scanner. The SOC710 comes supplied with a USB 2.0 'camera' cable which connects the camera's mini-USB data port (Figure 1) to an open USB 2.0 port on the computer. This is a 'generic' cable, and replacements can be purchased at a local electronics store.

Figure 1: Camera and Computer Back.

1. **1.** Connect the 12VDC power supply to the power connector (the power LED should illuminate).
   - **a.** The camera will make a whirring sound as the scanner moves into position.
2. **2.** Connect the MiniUSB cable provided.
3. **3.** Wait for the computer to recognize and install the *Lumenera*™ cameras and SOC USB device.
   - **a.** Please answer 'Yes' to any Unsigned Drivers/Continue Anyway prompts.
4. **4.** Follow the default settings given by Windows.

1.2.4 Determining the Correct COM Port

Since every computer is slightly different, the 'COM' port used by the SOC710 can change depending upon what devices have already been installed. In order for the instrument to work properly, the correct COM port must be designated to the software. In this step, the Device Manager is used to determine the correct COM port settings for the 710 Software. To open up the device manager panel to determine the COM port setting for the SOC710, perform the following steps:

1. Open the Device Manager by right-clicking on 'My Computer' and selecting Properties.
2. Select the 'Hardware' Tab.
3. Select the 'Device Manager'.

The device manager should open up on the desktop as shown in Figure 2. To determine the appropriate COM port for the SOC710:

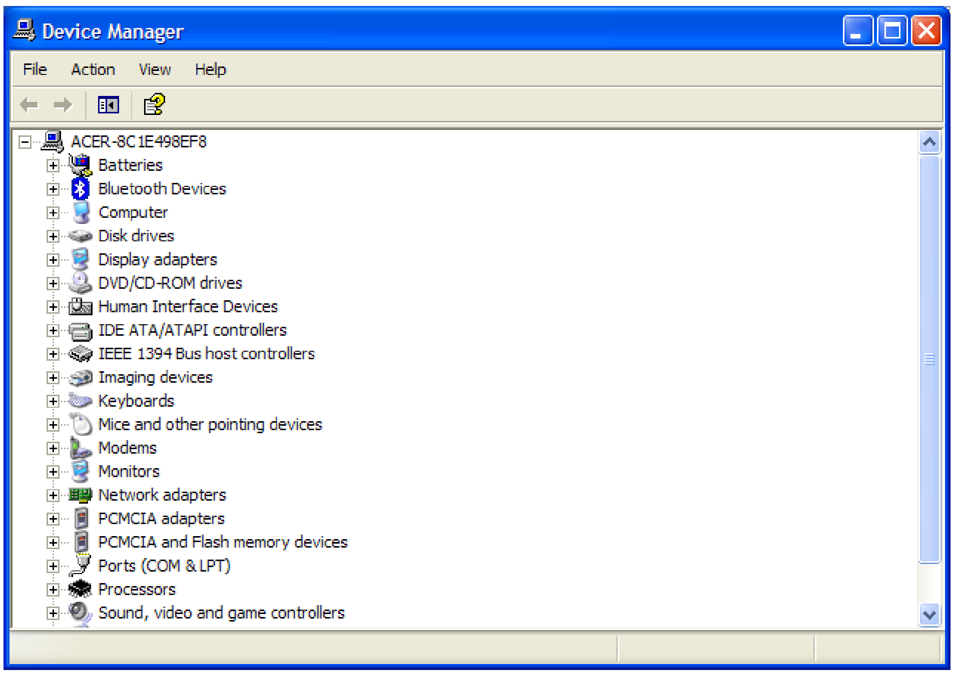
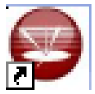


Figure 2: System Device Manager where COM Port Settings are Located.

1. Click on the '+' sign next to the 'COM' Ports tab and look for a COM Port labeled 'USB Serial Port'.

2. Make a note of the COM Port number. This will be used later on when the SOC710 Data Acquisition software is initialized.

1.2.5 Assigning the COM Port



Start the 'SOC710 Software' located under – *START / SOC710 Data Acquisition Software* or click on *SOC710 Data Acquisition Software* icon on the desktop.

The default COM port setting is COM4. If the default setting is not correct, the Scanner Settings Dialog Window will open first. Set the Scanner COM Port to the port recorded in the previous step and Press 'OK'. You will not need to do this again unless the computer is reconfigured.

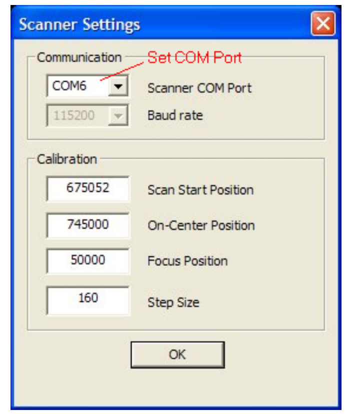


Figure 3: Scanner Settings Dialog Box.

There will be a pause as the focus camera moves into position and then the software will open two windows (Figure 4). The main interface will be displayed in front along with a second window behind it showing the video as seen through the focus camera.

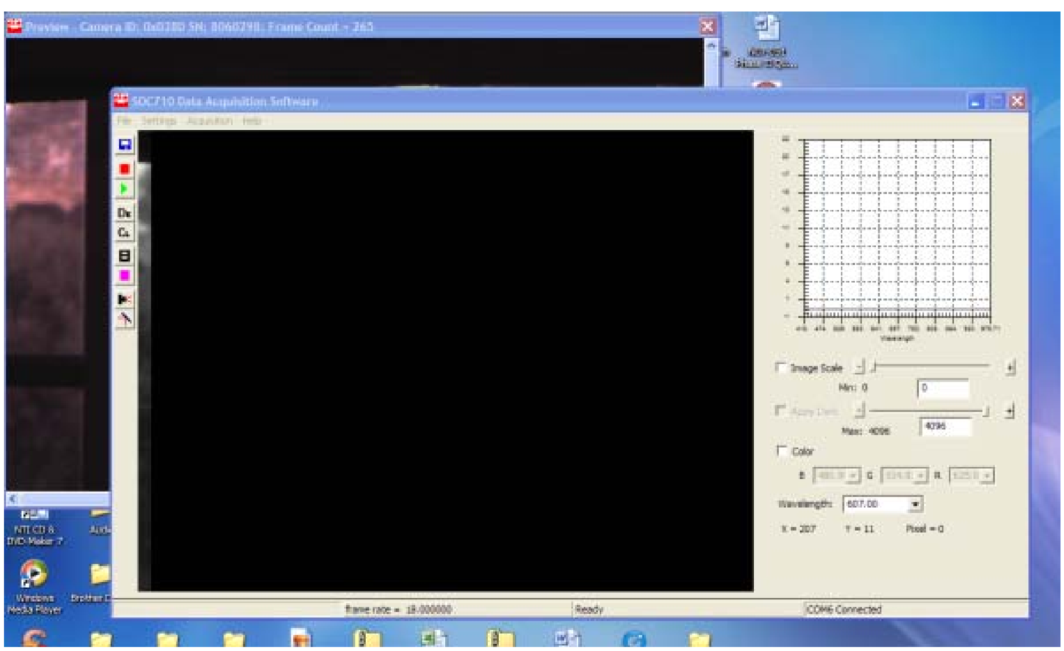


Figure 4: Main SOC710 Software Panel and Focus Window (behind).

1.2.6 Focusing the Camera

Bring the focus window to the front and adjust the focus of the camera by turning the focus wheel on the lens. Once this is completed, close the focus camera display by pressing on the *focus* button or closing the focus window. At any time you can recall the focus camera window by pressing on the *Focus* button located along the left side of the main panel.

1.2.7 Acquiring Spectral Images

To collect a spectral data cube, simply press on the scan button.

There will be a short delay as the camera moves to the beginning scan position and an image will then begin to form in the main window as the camera scans the scene from left to right. The software will automatically scale the display for best contrast. Moving the mouse over the collected image updates the graph in the upper right hand corner of the main display to show the intensity of the spectral values of the pixel located under the mouse.

NOTE

Generally, pixel values in the 200 range and above are adequate, however values in the 500 - 3000 range are recommended. Since the data is 12-bits, values over 4096 are saturated.

1.2.8 Saving a Spectral Image Cube

Now that a hyperspectral data cubes has been acquired the cube can be saved for further analysis. The data being collected is stored in the main memory of the computer and is NOT automatically stored as a disk file. In order to 'save' a cube for further analysis, the 'Save' button must be pressed on the main panel. It is not necessary for a full scan to be completed before saving the data, but only that portion of the image that was scanned will be stored.

NOTE

Data being collected is stored in the main memory of the computer and is NOT automatically stored to a disk file. To 'save' a cube, use the 'Save' button on the main panel.

When you press the Save button, the 'Save' dialog box (Figure 5) will open. There are several options for saving a cube. For now, select the *SOC 710 Standard* format (BIL with 32768 Byte header). This will save a file compatible with SOC's SRAnalysis Software.

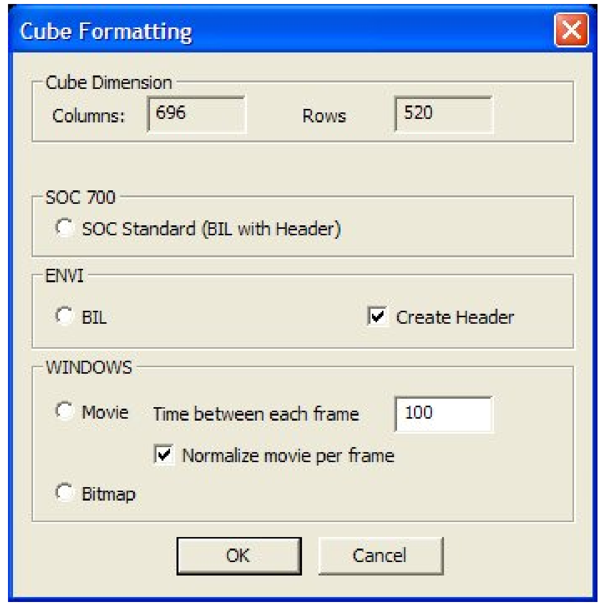


Figure 5: 'Save' Dialog Box.

Additional options are explained in the 'Saving Image Cubes' under the *Using SOC710 Data Acquisition Software* Section.

1.2.9 Calibration and Analysis (Using SRAnalysis Software)

Now that a cube has been saved, it can be opened for calibration and analysis using SOC's *SRAnalysis* software. Select File/Open from the Main Menu. This will bring up a file dialog box from which you can select the hyperspectral image cube just saved. The software will pause as the cube is loaded, then the display window in the software will show a copy of the image in the spectral band selected. Additional information on the SRAnalysis software can be found in the SRAnalysis User's Manual (Section 2.0).

Figure 6: SOC's *SRAnalysis* Calibration and Data Analysis Software.

1.3 Using the SOC710 Data Acquisition Software

This section provides additional information on the SOC710 Data Acquisition Software used to control the SOC710 spectral imaging system.

1.3.1 Software Overview

Through the SOC710 Data Acquisition Software you control the SOC710 spectral imaging system and use it to acquire and display hyperspectral image cubes.

The main graphical user interface (GUI) to the SOC710 Data Acquisition Software (shown below) is divided into three parts: The Main Display window, Spectrograph and Display Settings panel (right) and the toolbar/menu (left/top).

1.3.2 Main Display

The Main Display window (Figure 7) shows hyperspectral data as it is being acquired. As the system scans from left-to-right (Figure 8) the main display fills in across the screen until the data acquisition is complete. The characteristics of the display in the main display window are controlled through the display panel. The User can select a single band 'monochrome' display or a 3-band 'color' display. Although the software will automatically scale the display to fit the dynamic range of the data, a set of separate image scale sliders is available for custom scaling.

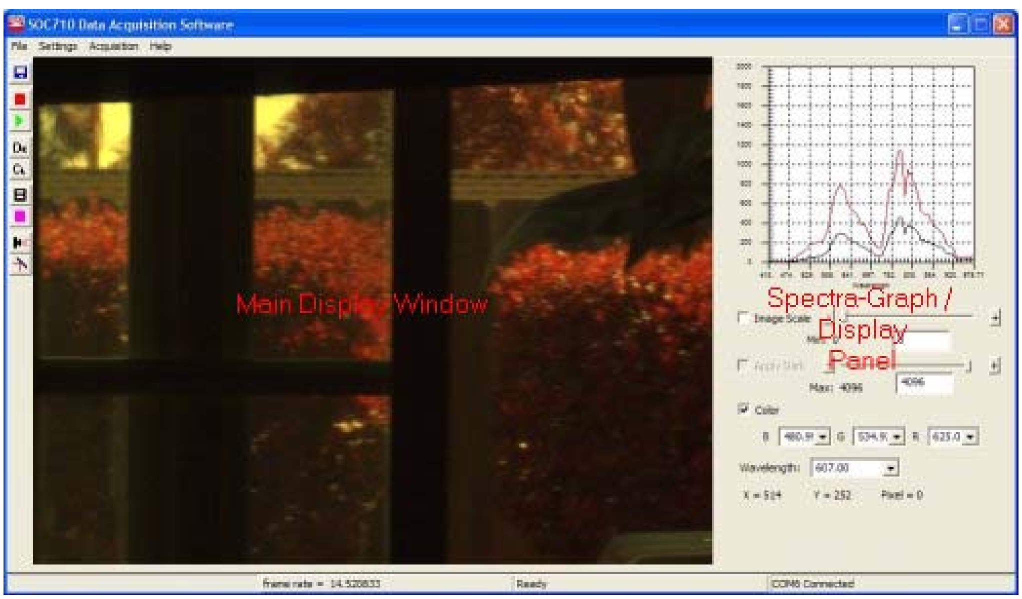


Figure 7: SOC710 Data Acquisition Software Main Window.

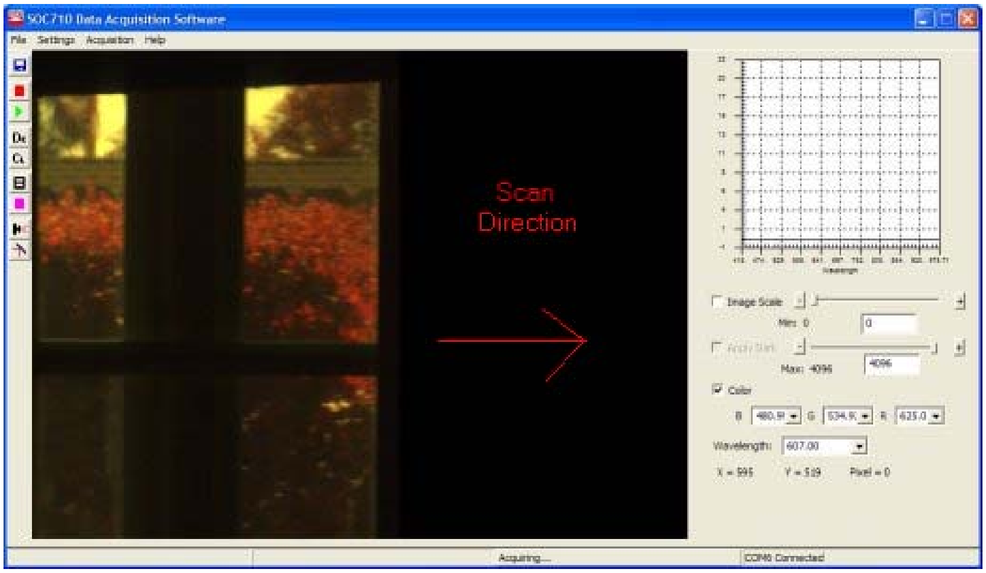


Figure 8: SOC710 Scanning Direction.

In addition to showing the progress of the spectral data acquisition, the main display window is also used for the spectral display (Figure 9), a live-video stream of the focal plane of the spectral camera at the center of the camera's field-of-view.

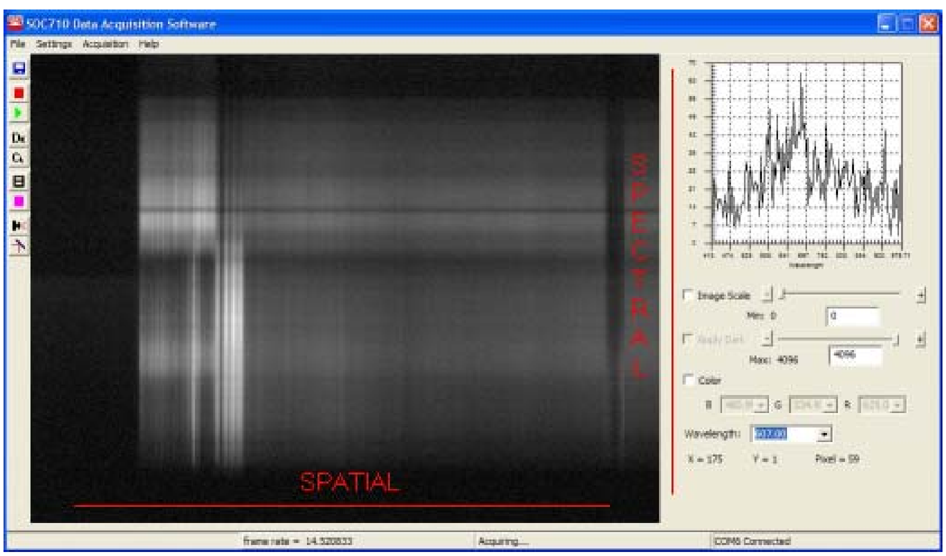
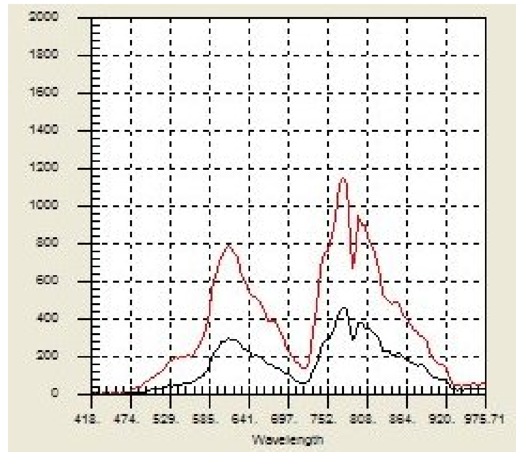


Figure 9: Spectral Display Showing Spectral and Spatial Dimensions at the Center of the Field of View of the System.

<u>1.3.3 Spectra-Graph/Display Panel</u>

The Spectrograph (Figure 10) becomes active during scanning and after an acquisition is complete. The Spectrograph displays the spectral intensity curve of pixels in the image as the cursor is passed over them. Right-clicking on a pixel in the image stores the current spectra in the display for comparison against other points in the image. The tool can also be used to check for saturation in the image as it is being acquired.

Figure 10: Spectrograph Showing Plot of Reference (Red) vs. Unknown (Black) Pixels.



In addition to the Spectrograph window, the Spectrograph/Display panel also contains tools (Figure 11) for adjusting how images appear in the main display.

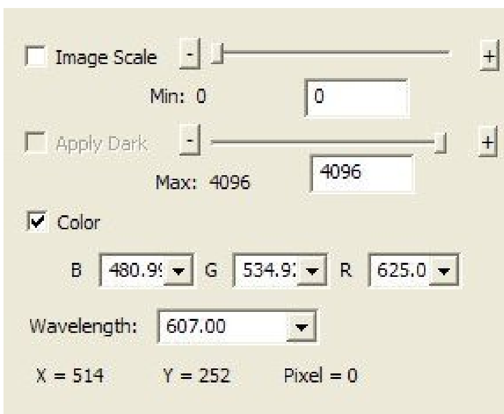


Figure 11: Display Settings.

- *Image Scale* – Is used to stretch the display values over a given data range.
    - Check the box to use image scaling.
    - Min – Is the minimum value over which to stretch the display.
    - Max – Is the maximum value over which to stretch the display.
    - Values below the minimum will be black, values above the maximum will appear white.
    - Image Scale is only applicable to non-Color display.
- *Apply Dark*
    - Check the box to dynamically apply dark frame subtraction to the displayed image.
    - This checkbox will only become active if a dark frame has been acquired.

- *Color/Wavelength* – Loads values from the three channels selected into Red, Green and Blue channels of the display for simulating color.
  - *B, G & R* combo boxes are used to select the wavelengths corresponding to each color.

- *X, Y, Pixel*
  - Reports the *X, Y* location of the cursor and the Pixel value for the wavelength selected.

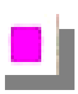
1.3.4 Toolbar and Menu

The toolbar and menu contain buttons and/or items that control the camera and the data acquisition. From both the menu and the toolbar the User can:

- Save Image Cubes
- Stop the recording
- Record Hyperspectral Image Cube
- Record Dark Frames
- Record Calibration Frames
- View the spectral display
- View the focus camera
- Open the Camera Settings Dialog Box
- Open the Scanner Settings Dialog Box

The menu contains two additional commands not found in the Toolbar; (1) Exit (which closes the program, and (2) Help | About (which provides information on the software version).

1.3.5 Focusing the System



Pressing on the focus button will bring the focus camera into position in front of the lens and open the focus camera window. Since the focus camera is located the same distance as the slit of the imaging spectrometer, an image focused via the focus camera will also be focused in the hyperspectral image cube.

Bring the focus window to the front (if it is not already) and adjust the focus of the camera by turning the focus wheel on the lens. Once this is completed, close the focus camera display by pressing on the *focus* button a second time or closing the focus window. At any time you can recall the focus camera window by pressing on the *focus* button.

NOTE

When adjusting the focus, be careful not to inadvertently adjust the ‘f’-stop of the lens. The f-stop is held in place by a small set screw on the lens. Changing the f-stop changes the radiometric calibration of the system. If the f-stop is changed, be certain to make a note of it and ensure that the appropriate f-stop value is used in the SRAnalysis software.

1.3.6 Spectral Display

The spectral display shows the spectrograph that is being projected on to the CCD for the on-center position in the field of view. Although there is no direct provision for viewing at positions other then the on-center position, the location of the on-center position can be changed through the scanner control panel. The image is rotated counter-clockwise 90 degrees from its actual physical orientation in the spectrometer in which the slit lies along the vertical dimension. In the display, the spectral dimension lies along the *y*-axis and the spatial dimension along the *x*-axis. The spectra go from shorter wavelengths (bottom) to longer wavelengths (top).

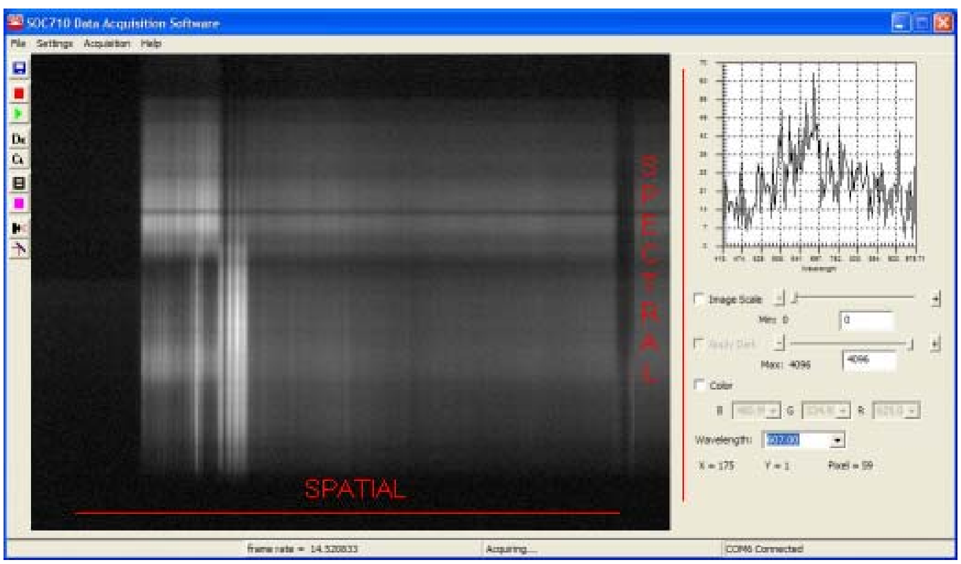


Figure 12: Spectral Display of an Outdoor Scene.

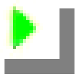
To bring up the spectral display window, click on the Spectral display button in the Main Panel. There will be a slight pause as the scanner positions the slit in the on-center position. The spectral display allows the User to see the spectral data for a single column in the on-center position.

The spectral display varies along the spatial dimension with each column corresponding to an individual pixel in the spatial domain along the entrance slit. Brighter values indicate a higher radiance reaching the sensor at that wavelength. The range of wavelengths goes from shorter at the bottom to longest at the top. White objects appear uniformly bright except at the ends of the wavelength spectrum due to fall off in the response of the camera. Proper calibration removes this effect.

In the image above, the left side of the display appears dark because the subject, and its image formed on the slit, was not well illuminated in that region.

The spectral display can be open only when the User is not acquiring hyperspectral image cubes; while informative, the spectral display is usually used only in aligning the optics in the camera.

1.3.7 Acquiring Image Cubes



Strictly speaking, there are three types of data cubes that can be collected by the system: image cubes, dark frame cubes, and calibration cubes. Dark frame and calibration cubes are small cubes, only 25 lines wide, and are used as the names imply; for dark frame subtraction and system calibration. This section covers the acquisition of image data cubes.

Pressing the collect cube icon on the toolbar moves the scanner into position and starts the system acquiring data. In normal orientation, the imager scans from left to right collecting columns of data. Each column represents a single frame of data. A frame in this instance means the equivalent of a video frame of data, 520 rows high by 128 bands deep.

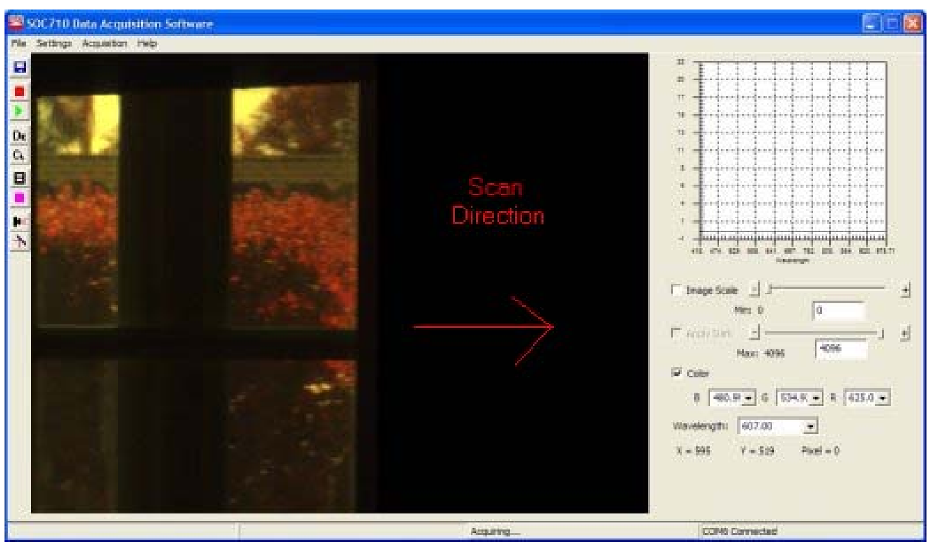


Figure 13: Scan Direction of Data Collection.

When 696 columns of data have been acquired the scanner will stop and a complete image ‘cube’ of data will be available for analysis. The ‘cube’ is 696 columns by 520 rows by 128 bands deep and is stored in what is commonly referred to as Band-Interleaved-by-Line format. This data is held in memory until the next scan.

Pressing the Stop button before a scan is complete will stop the camera from acquiring any more data and return the scanner back to its initial scan position. The data that has been recorded is resident in the computer's memory and can be saved just as a complete scan could be. Where data was not recorded, the image cube will contain zeros (0s).

1.3.8 Reviewing the Data Using the Spectrograph

In the Spectrograph/Display panel a plot of individual pixels in the data can be reviewed as the data is being collected and the exposure time of the camera can be adjusted for optimum signal strength in the spectral region of interest without saturation. As the cursor moves over the image, the location of the cursor is reported in the lower right corner of the display panel and a plot of the data at the pixel is displayed in the Spectrograph plot window.

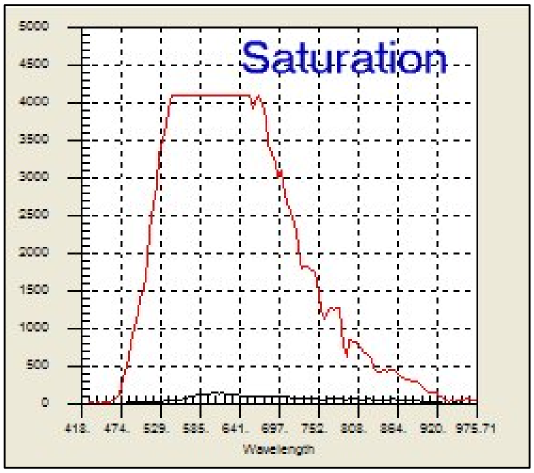
Generally speaking, spectral values in the 200 range and above are adequate, but values in the 500 to 3000 count range are recommended. Since the data is 12-bits, values over 4096 are saturated. Because the spectral response of the silicon focal plane array used in the system is not uniform over the entire 400-1000nm spectral range, the spectral plots will appear 'bell' shaped, with lower response at each end of the spectrum.

NOTE

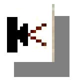
If the spectral region of interest is at either end of the spectrum, saturation in the more sensitive central region of the spectrum may be unavoidable in order to get adequate signal-to-noise in the less sensitive tail regions.

To look for saturated pixels, interrogate pixels in the brightest part of the image first. If a pixel is saturated, its plot will appear as in Figure 14. While saturation is not desired, it might be necessary with certain samples to allow unimportant areas of the scene saturate in order to obtain adequate dynamic range in other parts of the image.

Figure 14: Saturated Pixel.



1.3.9 Camera Settings



Depending on the subject and lighting conditions the User may want to adjust both the exposure (integration time) and gain settings on the CCD. These settings can be accessed through the camera settings panel. To bring up the camera settings panel, press the camera settings button on the toolbar.

Integration time is measured in milliseconds (ms). Lengthening the integration time will compensate for poor lighting or dim subjects, but will also lengthen the time required to capture not only individual columns of data, but the image cube as a whole. As in any other camera, this can result in smear at very long integration times.

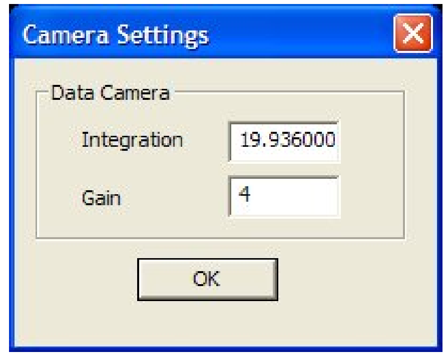


Figure 15: Camera Settings Panel.

Electronic gain can be increased as an alternative to or in addition to lengthening the integration time, however since the gain is electronic, noise in the image will also increase correspondingly. A gain value of ‘1’ is unity, i.e. no gain. The scale is linear, with a value of ‘2’ providing twice the gain and a value of ‘3’, three times the gain. For the best signal-to-noise ratio, increasing integration times is the preferred method; however increasing the gain provides a good trade-off between keeping the speed of the data acquisition fast enough to prevent smear, but also getting adequate dynamic range to make the data meaningful.

1.3.10 Scanner Adjustment

Scanner settings are set at the factory for the configuration of the instrument at the time of shipping. It is possible to adjust the internal scanning mechanism in the SOC710 via the scanner settings panel, however it is not recommended unless the lens has changed or the system has been modified or damaged for some reason. It is possible to change the on-center position to view different portions of the field-of-view via the live-video/spectral-display window, however the User should record the original on-center position and return it to this value once experimentation has been completed.

To bring up the scanner settings control panel and adjust the scanner settings, press on the scanner settings icon in the toolbar. Doing so will bring up the Scanner Settings Dialog Box (Figure 16).

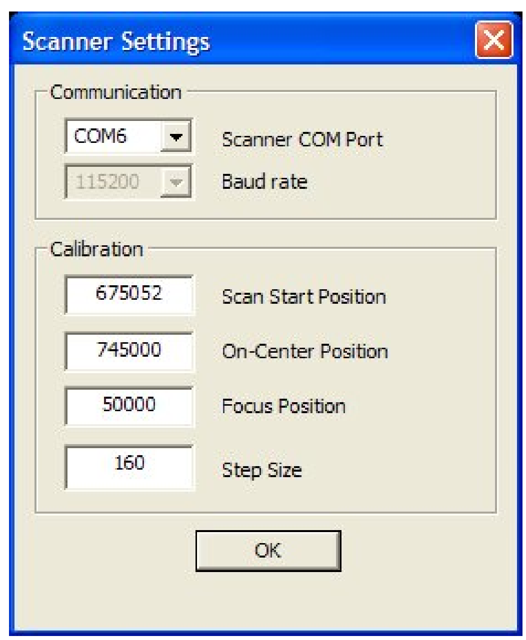


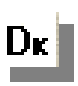
Figure 16: Scanner Settings Dialog Box.

The Scanner COM Port sets the COM port through which the instrument communicates with the computer. Under normal circumstances, this value does not change. However, if the User adds a COM Port device, such as a Bluetooth device or for some other reason the value of the COM port changes, it can be updated through the Scanner Settings Panel. The Baud Rate setting is fixed at 115,200 bps and cannot be changed except by directly editing the scanner settings file located in the program files directory. Adjusting the Baud Rate is NOT recommended.

Scan Start, On-Center, and Focus positions are set at the factory. These positions correspond to the location of the scanner at the 'Start' of a scanned image, at the 'Center' (spectral display position) of the scanned image and the position of the scanner when the focus camera is centered on the lens. Modifying these values is not recommended unless the factory lens has been replaced or other significant modifications have been made to the system.

Step size dictates how many 'steps' the scanner makes between columns recorded. The step size is determined by the instantaneous field of view of the lens and is set to yield 'square' images, i.e. images that are not distorted spatially in either dimension. If the lens is changed and the IFOV of the pixels has correspondingly changed, then the Scan Start and Step Size parameters may need to be modified.

1.3.11 Dark Frame Calibration



Dark frame noise is present in any electronic imaging system. Dark noise is the electronic noise present in the system when it is not illuminated. Fortunately, dark noise is easily compensated for. By periodically collecting a dark frame, the User takes a measurement of the dark noise on the CCD on a per-pixel basis and can subtract its effects from the collected image.

To collect a dark frame, cover the lens with the lens cap provided with the system and press on the Dark Frame Icon on the toolbar. The scanner will move the camera into position and collect a dark cube consisting of 25 spectral images and prompt the User to 'Save' the dark frame to a file. Once the dark frame has been collected, the values at each pixel are averaged over the 25 data collections and used for dark frame calibration of collected data.

NOTE

It is recommended, but not strictly necessary, to 'Save' the dark frame to a file in order for the SOC710 Data Acquisition Software to perform on-the-fly dark frame subtraction since the data is kept in memory, however this file is also used in the SRAnalysis calibration software which will not have access to the data unless it is saved to a file.

After you have collected a dark frame, you may apply it directly to the data being displayed when scanning by selecting the check box 'Apply Dark' on the display panel. The dark value will be subtracted ONLY from the displayed data. In order to perform dark frame subtraction on the entire dataset, the Dark Frame must be 'saved' and used in *SRAnalysis* or other hyperspectral image processing package.

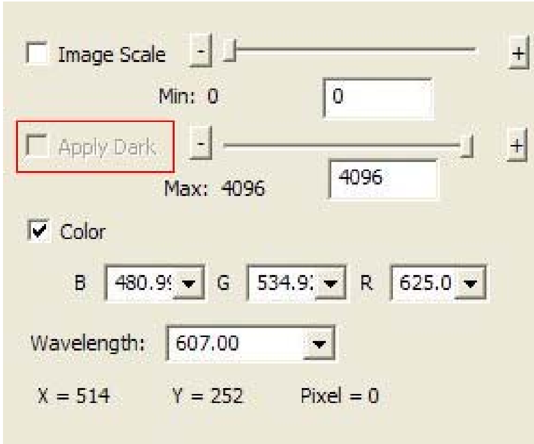


Figure 17: Apply Dark Checkbox Becomes Active when a Dark Frame has been Collected.

After you have collected a dark frame, you may apply it directly to the data being displayed when scanning by selecting the check box 'Apply Dark' on the display panel. The dark value will be subtracted ONLY from the displayed data. In order to perform dark frame subtraction on the entire dataset, the Dark Frame must be 'saved' and used in *SRAnalysis* or other hyperspectral image processing package.

1.3.12 Display Options

There are several options available for displaying and examining the data as it is being acquired through the display control panel (Figure 18). The first is the choice of whether color (three bands) or monochrome/grayscale (one band) will be shown. During the data acquisition and afterwards, the choice of band or bands to be displayed can be modified interactively.

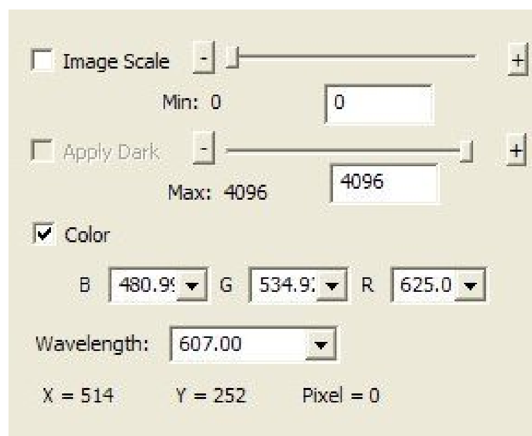


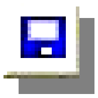
Figure 18: Display Panel.

The color checkbox is used to toggle between Color and Grayscale display. The B, G and R combo boxes determine the three bands that will be used for Blue, Green and Red respectively. The bands in the combo boxes can be changed be selecting a new band through point-and-click OR once the combo box is activated, by using the mouse scroll wheel. Using the mouse scroll button will cycle through the bands up or down depending upon which way the mouse scroll wheel is moved.

Similarly, the 'Wavelength' box is used to set the band to be displayed when a Grayscale (or single band) is to be displayed. This combo box works the same as the G, R and B combo boxes for the color display, including the ability to scroll through the bands using the mouse scroll wheel.

When Grayscale is chosen, it is possible to 'Scale' the image using the 'Image Scale' sliders. Checking the 'Image Scale' checkbox turns this functionality on. Setting the 'min'-imum and 'max'-imum values 'stretches' the grayscale display over the region between minimum and maximum. This can be useful when trying to view images with a large dynamic range, allowing the User to accentuate darker regions in image data containing a very bright source.

1.3.13 Saving Image Cubes



When you press the Save button, the 'Save' dialog box (Figure 19) will open. There are several options for saving a cube:

- *SOC 710 Standard* Format:
  - This will save a file compatible with SOC's SRAnalysis Software.
  - The values are short (2-byte) unsigned integers in Intel format.
  - The dimensions of the cube are 696 Columns (Samples) by 520 Rows by 128 Bands
  - The data is stored in Band-Interleaved-by-Line format with a 32768 byte header.

- ENVI™ Format:
  - This will save a file compatible with the ENVI Image Processing Package.
  - The values are short (2-byte) unsigned integers in Intel format.
  - The dimensions of the cube are 696 Columns (Samples) by 520 Rows by 128 Bands.
  - The data is stored in Band-Interleaved-by-Line format with a zero (0) byte header.

- Movie
  - Creates an AVI movie file with a 100 millisecond pause between frames of the annotated bands displayed in a loop.

- Bitmap
  - Creates a Bitmap file of the current display.

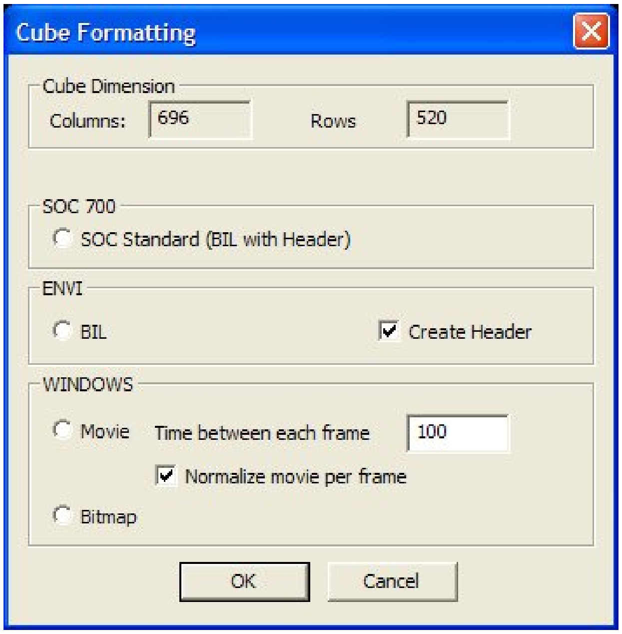


Figure 19: 'Save' Dialog Box.

1.4 Best Practices and FAQs

While SOC has done everything possible to make the SOC710 an enjoyable and easy to use instrument for gathering quality hyperspectral data, it ultimately depends upon the User of the device to determine the quality of data taken from the system.

1.4.1 Lighting

By their nature, hyperspectral imaging systems, which spread light out much more 'thinly' over the focal plane then conventional cameras, require lots of light. The SOC710 performs very well on subjects in either direct or indirect sunlight. When using the system indoors, SOC recommends the use of broadband photographic lighting with Tungsten lamps. A diffuser is also recommended to keep the amount of specular reflection off of surfaces to a minimum and thereby making the most of the dynamic range of the instrument. Outdoors, a conventional linear polarizing filter can also be used to keep down hot-spots from polarized surfaces.

1.4.2 Lenses

The SOC710 comes equipped with a Schneider Xenoplan™ lens. All lens designs make some compromise in performance over the spectral region they were designed to cover. The Schneider Xenoplan™ lens family has been designed for exceptional performance in the visible portion of the spectrum and is near infrared corrected. Lower quality, non infrared corrected lenses, are not recommended as the quality of the images in near infrared portion of the spectrum will suffer. Even with a near infrared corrected lens such as the Schneider some defocusing of the image occurs at longer wavelengths. This is particularly apparent at lower f-stop settings (< f8). For the best quality spectral image cubes, adjust the f-stop of the lens to the highest value possible while still collecting enough light to provide adequate SNR.

Care must be taken when replacing the lens not to let dust or water enter the system. Also, as part of the optical train, after changing lenses a recalibration of the system is recommended.

1.4.3 Reflectance, Radiance or Counts

A CCD pixel records voltages which are digitally transformed into 'Counts' based upon the illumination of the pixel. Without calibration, these values are meaningless by themselves except as how they relate to other pixels within the image, where more counts means a 'brighter' pixel.

SOC performs a sophisticated radiometric and spectral calibration of your instrument at the factory. This radiometric calibration allows the direct translation between counts and radiance.

However, in order to measure reflectance, it is generally necessary to have a reflectance standard in the image at the time the data is taken. By using a reflectance standard the illumination conditions can be 'normalized' out of the data. If your goal is to measure reflectance, then a reflectance standard such as Halon or a flat gray reflectance panel is an absolute necessity.

2.0 Spectral Radiance Analysis Software

2.1 Introduction

The Spectral Radiance Analysis Toolkit (SRAnal) code provides the basic capability for data calibration, spectral correlation, image manipulation and display of the data collected by the SOC 710 hyperspectral imager system. This document provides a User's Guide to the functionality of this code as well as an overview to the spectral processing techniques used.

The SRAnal code is a PC/Mac/Linux software package that provides a basic tool kit for performing spectral correlation analysis on hyperspectral image cubes. The code is written in Java and will run on any computer or workstation that has the Java Virtual Machine (JVM) 1.6 or higher installed. The SRAnal standard installation for Intel/Windows based platforms automatically sets up the run time environment and executable program. JVMs for other platforms are available for download from www.sun.com. Figure 20 shows the User Interface (UI) for the SRAnal code.

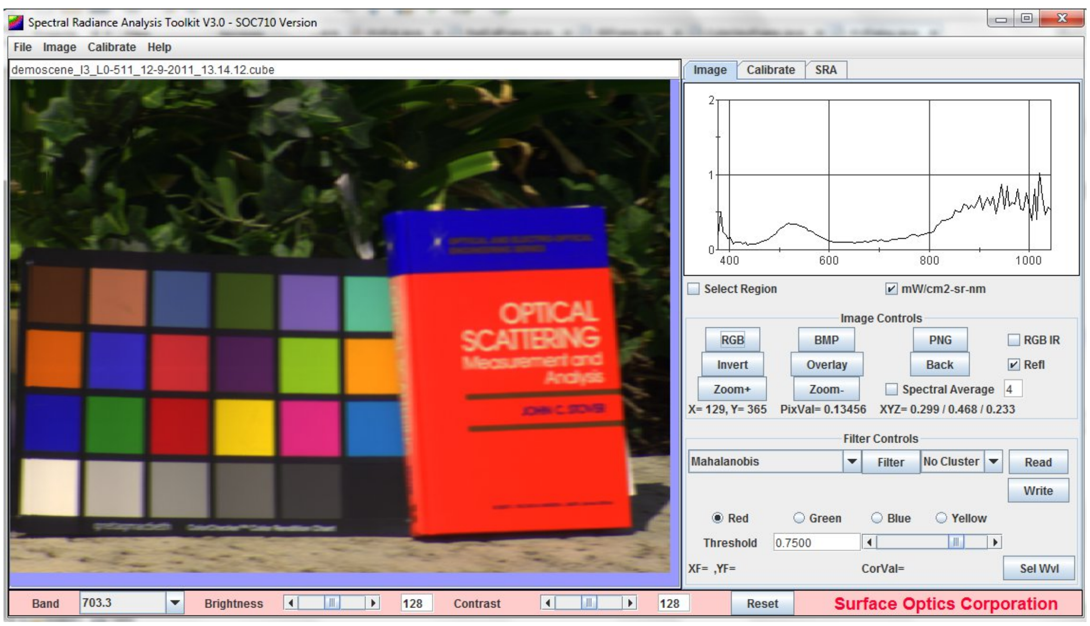


Figure 20: SRAnal User Interface.

The SRAnal interface has three tabs for loading, calibrating and processing hyperspectral image cubes and two display panels for viewing images and spectral plots. The menu functions and the functions of the controls are described below. Many of the functions are available as both menu selections as well as buttons on the Tab panels.

2.2 File Menu

The *File* menu, shown in Figure 21, loads and saves image cubes and also allows the user to save float formatted calibrated cubes and sub-cubes for input into other applications (e.g., ENVI, MATLAB). The *Quit* button exits the application.

Figure 21: The File Menu.

2.2.1 Open and Save Menu

The *Open* button opens a file selection dialog box for selecting a hyperspectral image cube. The code reads Band Interleaved by Line (BIL) format (line 1, band 1; line 1, band 2; … etc) image cubes that are produced from the raw data stream saved from the SOC-710 sensor system. The cubes are 696 by 520 pixels by 128 bands, stored as 16 bit integers plus a 32768-byte header for a total image size of 92.8 Mbytes. Image cubes are typically saved with a ".cube" or ".cub" extension, but this is not a requirement of the software.

The *Save* button opens a dialog box for saving and/or renaming modified image cubes after calibration or re-calibration.

2.2.2 Save Float and Define Float Sub Cube Menu

The image cubes are saved as 16 bit shorts, with the calibration information stored in the header or footer of the file. For accessing the image cube data from other applications the *Save Float* and *Save Band Image* options are available. *Save Float* saves the data as calibrated, 32 bit floating point numbers with a 32768 byte header in BIL format. These image cubes cannot be re-calibrated.

The user can also save sub-cubes in float format using the *Define Float Sub Cube* menu item, which opens up the dialog box shown in Figure 22. The user can select the start/stop row and column of the sub image as well as the number of beginning and ending spectral bands to skip. The band selection also accounts for the spectral band averaging option, which is described below. The float and sub cube images can also be read and processed by SRAnal, but they cannot be re-calibrated.

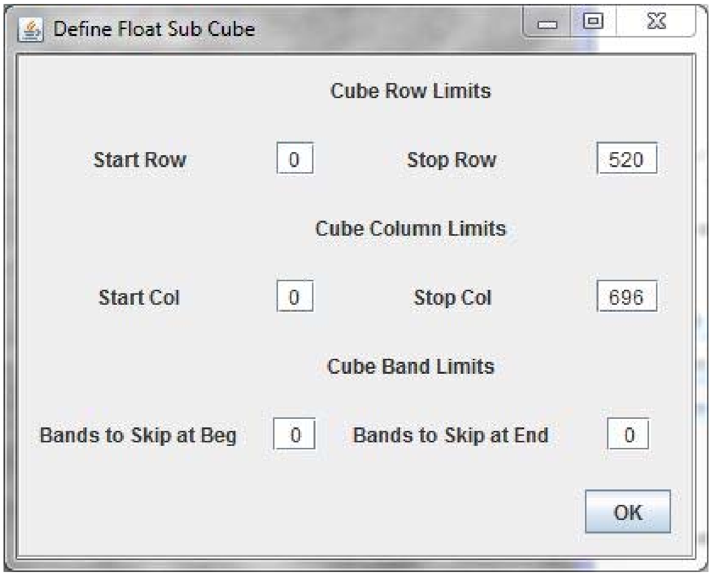


Figure 22: Define Float Sub Cube Dialogue Box.

2.2.3 Save Band Image Menu

The *Save Band Image* menu item allows the user to save a particular image plane (selected using the *Band* combo box described below) as a file of space separated (x,y) pixel values in text format. There is a one line header with the original cube file name and the wavelength. The pixel values are in the selected units of the display (counts, radiance or reflectance).

2.3 Image Display Panel

The *Image Display Panel*, Figure 23, displays individual gray scale image planes from the spectral cube as well as RGB integrated images, correlation image results and correlation overlay images generated by SRAnalysis. Brightness and contrast for the display can be adjusted using the Brightness/Contrasts Controls located at the bottom of the image window. A wavelength selection combo box is also located at the bottom of the window that allows stepping through the individual bands of the cube displaying the corresponding gray scale image as seen by the sensor.

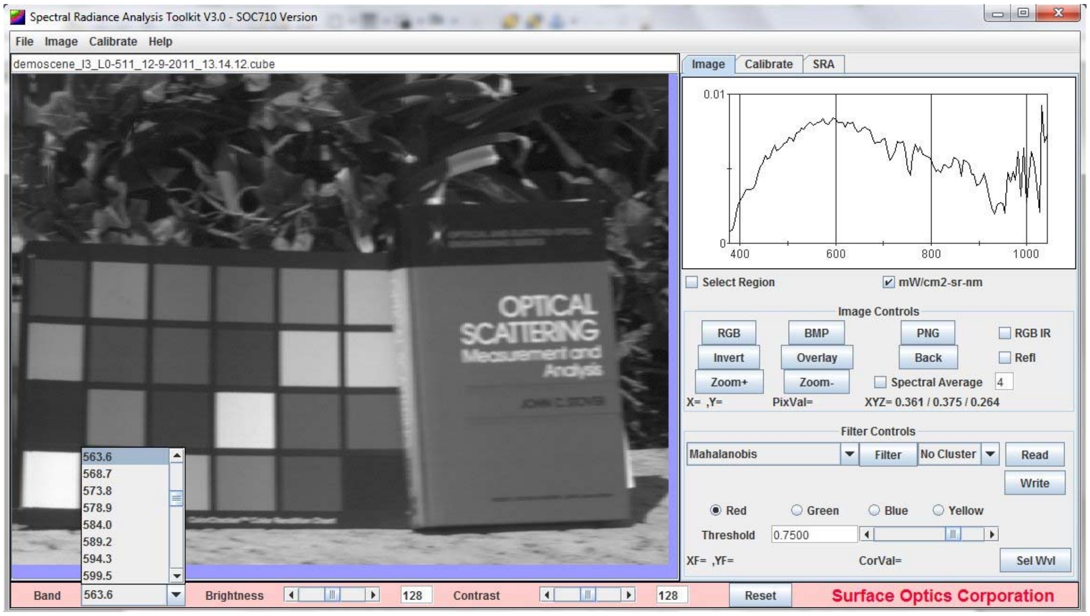


Figure 23: The Image Display Panel.

2.3.1 Spectral Display

The spectral plot in the upper right corner of the window, and shown in Figure 24, displays the full spectrum for the pixel pointed to in the image display. The units are either counts, radiance or reflectance depending on the calibration option selected, which is described below.

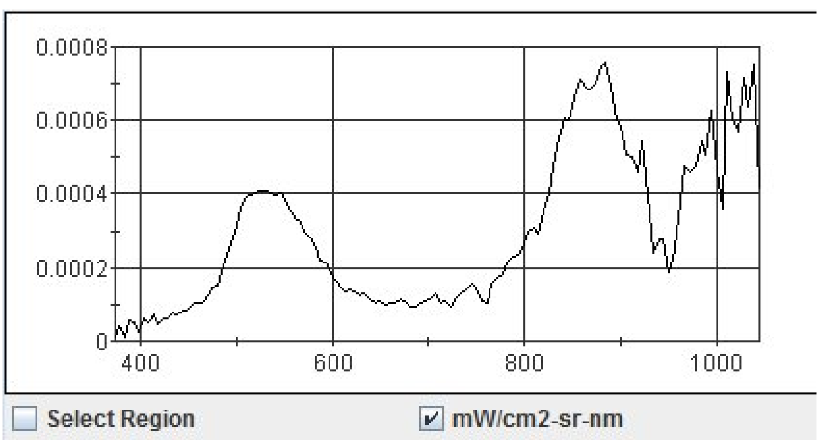


Figure 24: Spectral Display.

The *mW/cm2-sr-nm* check box toggles between radiometric units and integer counts if the data is calibrated. Note: In order to display calibrated radiances or reflectances, the user must first perform a calibration of the data cube as outlined in the calibration section of this manual. If a calibration has not yet been performed on the data, then the radiance checkbox will be disabled.

The *Select Region* check box allows the user to select a region of pixels to be spectrally averaged, or to outline a target region. This process will be described below.

2.3.2 Brightness/Contrast Controls

Two scroll bars, shown in Figure 25 below, control the brightness/contrast of the displayed image. The *Reset* button resets the brightness/contrast values to the original setting.

Figure 25: The Brightness/Contrast Panel.

2.4 Image Controls Box And Image Menu

The *Image Controls Box*, shown in Figure 26, provide controls for generating color images, modifying the display and overlaying results and also for saving the displayed image. These functions are also available from the *Image Menu*. The status line along the bottom of the box provides information on the pixel pointed to in the image display: (x,y) position, the pixel value in the selected units (counts, radiance or reflectance), and the XYZ color coordinates of the pixel, described below, computed using the tri-stimulus response function and a selected standard illuminant.

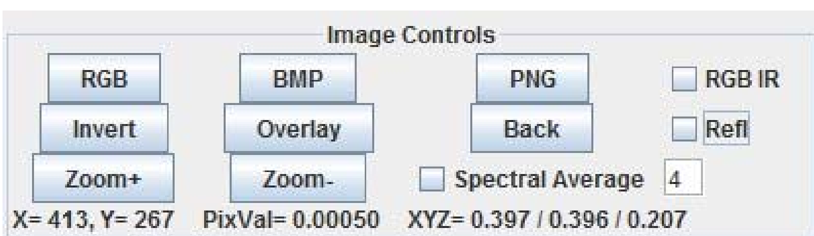


Figure 26: Image Control Box.

The basic XYZ calculation is based on the integral of the spectral radiance with the tri-stimulus values. In reflectance mode, the spectral irradiance illuminating the scene has been normalized out. Using the *Illuminant* menu item, located under the *Calibrate Menu* and shown in Figure 27, the user can select a standard spectral illumination definition for the calculation. The calculation is specified in ASTM paper 308.

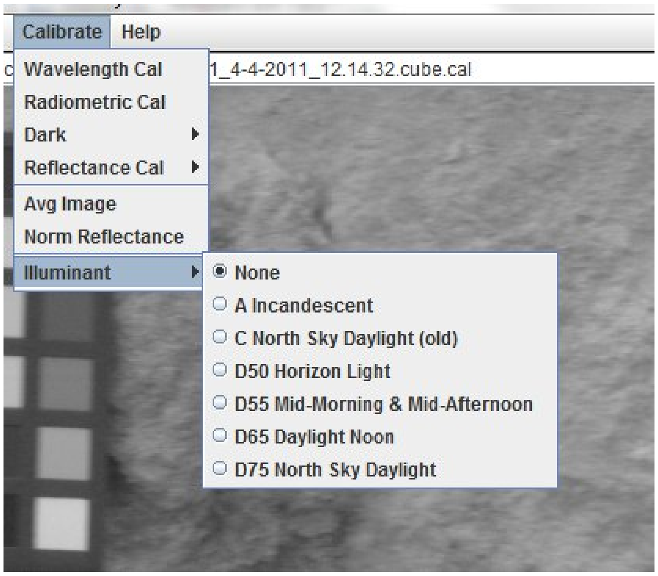


Figure 27: Selection of Standard Spectral Irradiance for XYZ Calculation.

2.4.1 Reducing the Number of Bands: Spectral Average

The user can reduce the number of bands in the image cube using the *Spectral Average* check box and adjacent text box. Checking the box will sequentially average N bands, where N is the number in the adjacent text box. All spectral filters will need to be reselected, or re-read in from a file. This is done on the fly, and can be reversed by unchecking the box. To save the reduced resolution image cube for subsequent processing, use the *Save Float* option, but this action cannot be reversed.

2.4.2 Generating and Saving Color Images

Pressing the *RGB* button produces a color image from the data by integrating the spectra for each pixel with the tri-stimulus response functions to produce X, Y Z color values which are assigned to the RGB channels of the image display, shown in Figure 28.

The *RGB IR* check box provides an alternate RGB model, shown in Figure 29, which emphasizes the NIR bands (700 to 900 nm). This is useful in agricultural applications where the user wants to focus on the longer, non-visible wavelengths in the image. In this case, the red channel is replaced by the NIR bands, the green channel is replaced by the usual tri-stimulus red calculation, and the blue channel is replaced by the tri-stimulus green calculation. The data in the blue end of the spectrum is ignored for this option.

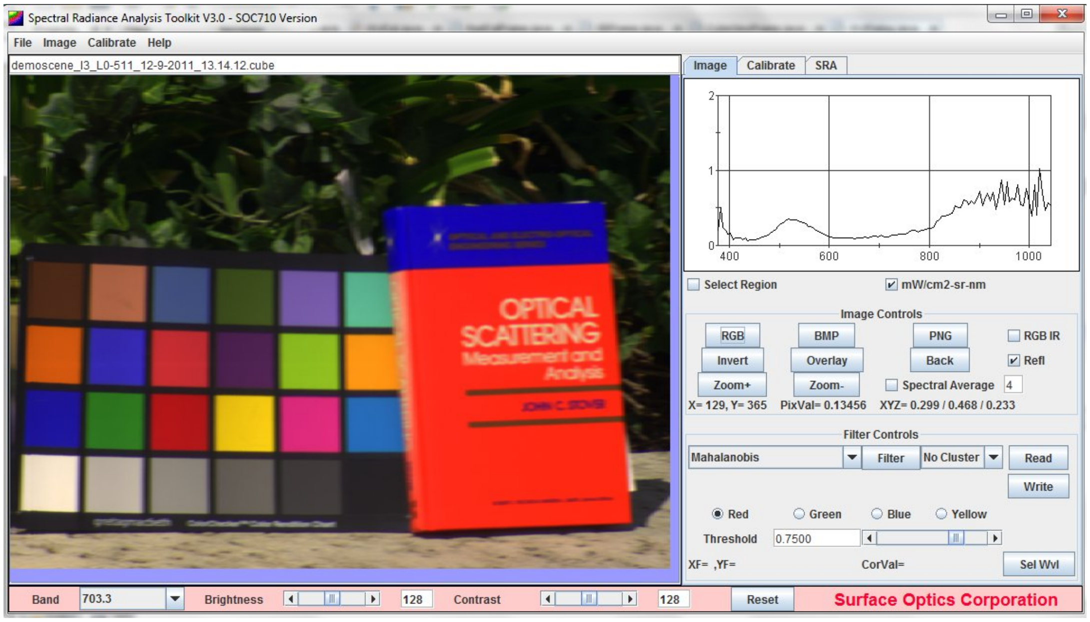


Figure 28: RGB Image Display.

The image in Figure 29 shows live vegetation as well as a wreath of artificial leaves, which is obvious in the RGB IR image because the fake leaves do not exhibit the high NIR reflectance due to chlorophyll, which is seen in the live plants.

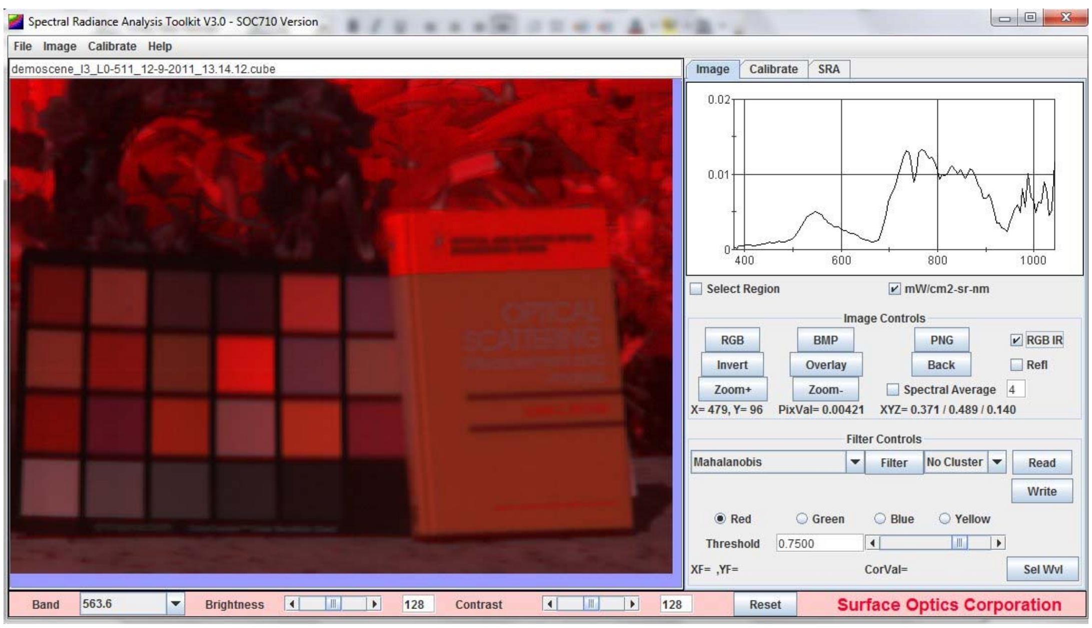


Figure 29: *RGB IR* Image Display.

2.4.3 Changing the Display: the Overlay, Invert and Back Buttons

The *Overlay* button overlays the current correlation map result with the current image display (gray scale or RGB) and displays the result in the image display window. Results of multiple correlation operations can be overlaid on the same image, in effect displaying the effect of OR'ing the results of multiple correlation operations, this will be described in the spectral filtering section below.

The *Invert* button toggles the display between an inverted scale and the original scaling. Figures 28 and 30 show a color image and its corresponding inverted image.

The *Back* button returns the display to the original image after an *Overlay* operation.

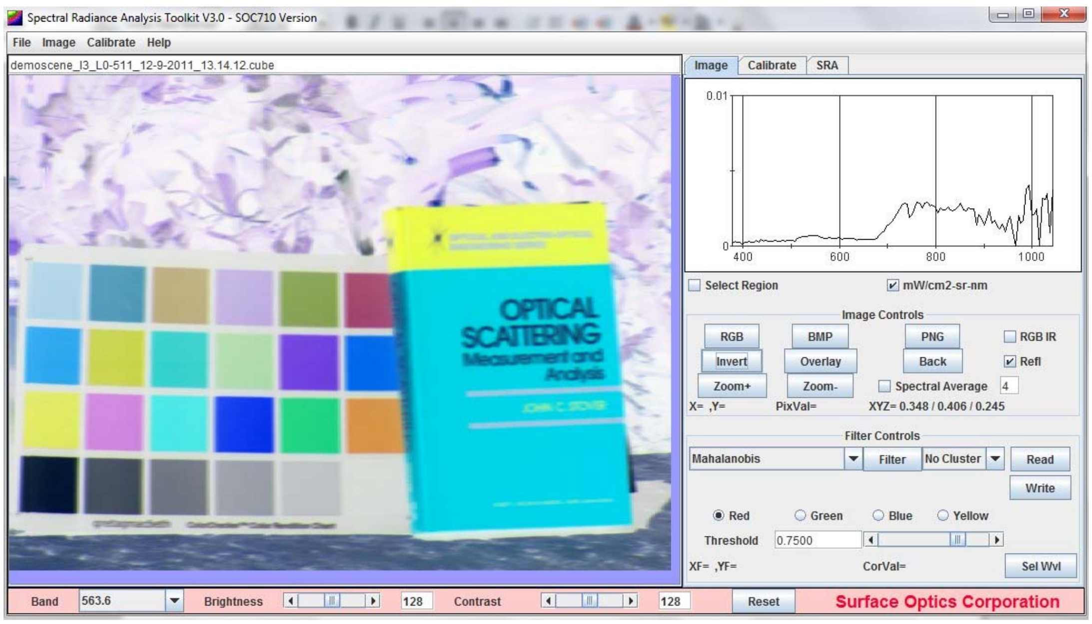


Figure 30: Inverted Color Image Display.

2.4.4 Saving the Image : the *PNG* and *BMP* Buttons

The *BMP/PNG* buttons produces a Windows bitmap (.bmp) or Portable Network Graphics (.png) image file of the current image in the display window, including the results of any filtering and overlay operations. The image file is written to the same directory, and has the same name as the image cube with the extension ".bmp." or ".png". Note: this operation will automatically overwrite image files with the same name. If the user wants to generate multiple result images from the same image cube, the image file should be manually renamed after each operation.

2.4.5 Spatial-Spectral Images: the *Cube View* Menu Item

Other views of the image cube are also useful for providing insight into the spectral data. This is provided through the *Cube View* Menu Item, found under the *Image* Menu. This brings up the *Cube View* window which provides a Column-Band or Row-Band Image, shown in Figures 31 and 32, and which can be toggled using the Combo Box.

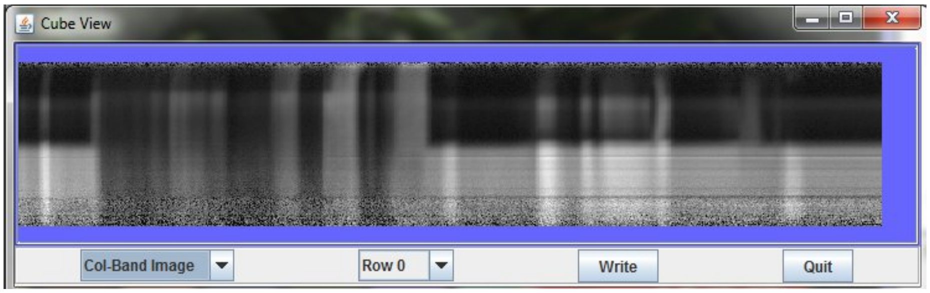


Figure 31: Cube View: Column-Band Image.

The row or column displayed is selected with the *Row/Column* Combo Box. Also, a 2D text file of the Row/Col selected image is saved using the *Write* button with the original file name with the type/location appended to the name.

Notice the phenomenology that can be observed in the spatial-spectral images. In Figure 31, the Row 0 image is comprised of vegetation (see Figure 28). The Column-Band image clearly shows the chlorophyll region (> ~700 nm) as the white band across the bottom of the image. This is clearly missing in the portion of the image comprising of the artificial plants. Also notice the bright stripe in the dark region of the image; this is the green (~550 nm) reflectance peak, which is also spectrally shifted for the artificial leaves.

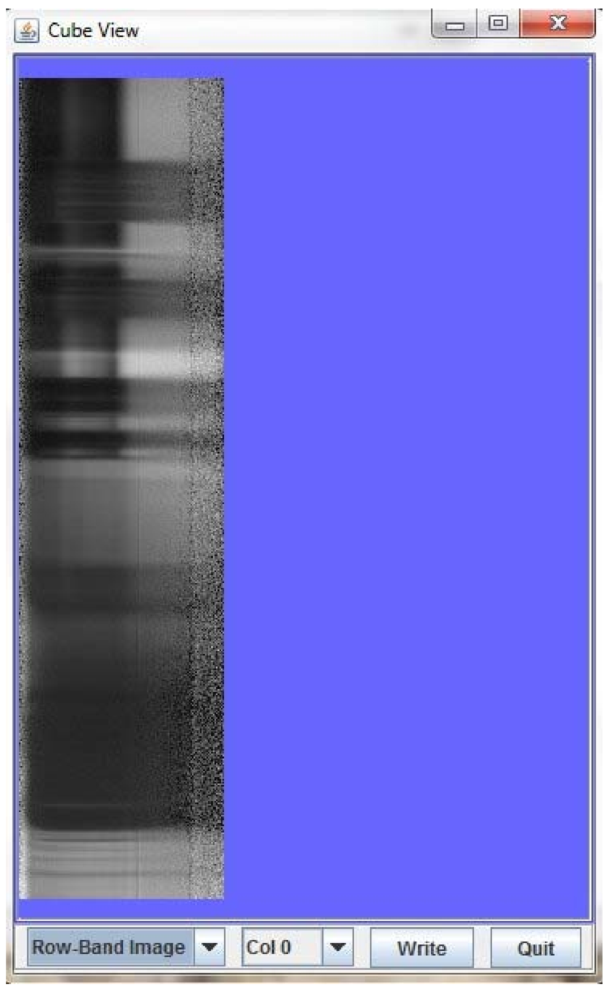


Figure 32: CubeView: Row-Band Image.

2.5 Spectral Processing: The *Filter Controls* Box

The various buttons and combo and text boxes in the *Filter Controls Box*, shown in Figure 33, on the bottom right side of the *Image Tab* provide functions for spectral filtering, spatial filtering, filter selection and display. Spectral filters can be read in from stored text files or can be specified directly from the image using the *Select Region* tool in the software, which is described below.

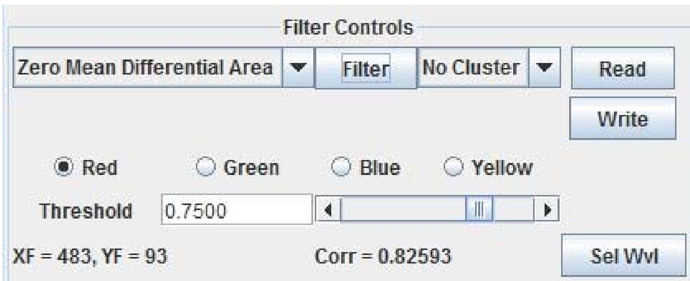


Figure 33: *Filter Controls* Box.

2.5.1 Defining filters from the Image: the Select Region Tool

Checking the *Select Region* check box allows the user to select a spectral filter from the image display panel. The user left-clicks the mouse button on the desired pixel to select that spectrum as the filter kernel. Holding down the mouse button while dragging the mouse across the image selects a region of pixels that are averaged to define the filter.

Figure 34 shows the filter box defined in the *Image Display Panel* and the spectral filter associated with it plotted in the *Spectral Display Panel* in red along with the current pixel's spectrum.

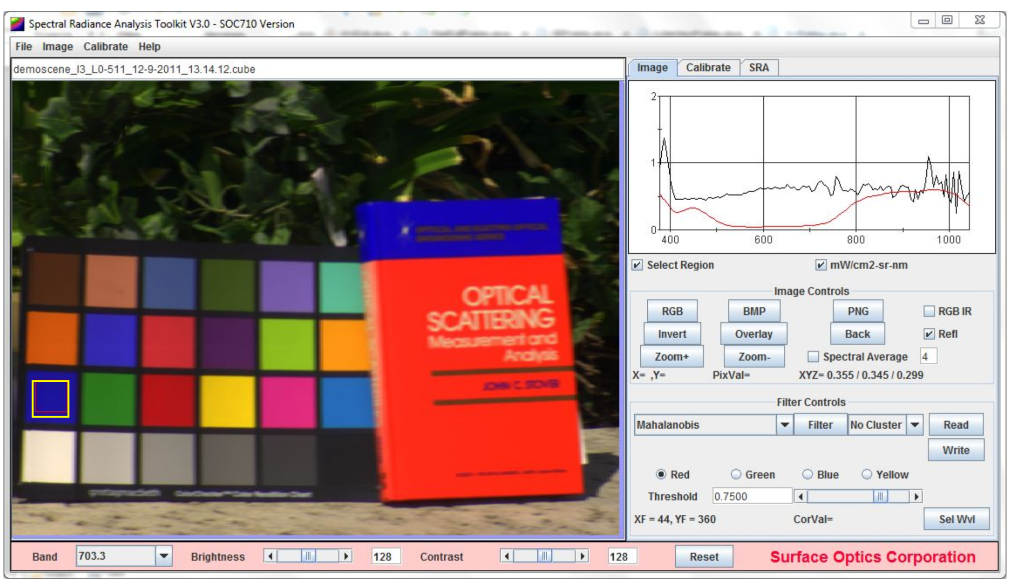


Figure 34: Spectral Filter Selection from Pixels in the Image Display.

The user can also select a region as a polygon by using a series of left-clicks around the desired region of interest. The region is closed by a right click. An example of a region defined using the polygon method is shown in Figure 35, where a leaf has been outlined in the upper left corner of the image.

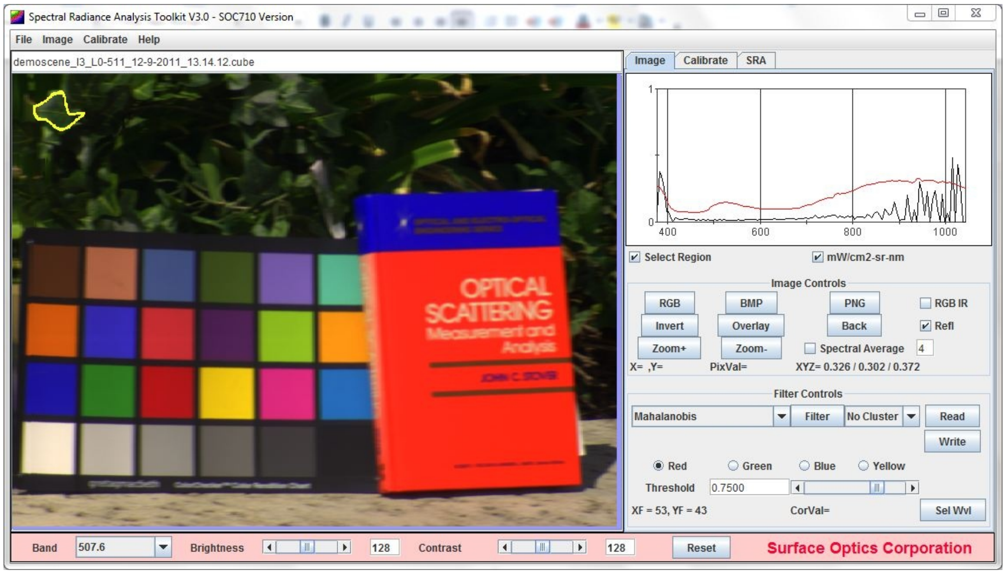


Figure 35: Polygon Region Selection of Leaf in Upper Left Corner of Image.

2.5.2 Loading and Saving Filters

The *Read* button opens a dialog box for selecting a filter spectrum from a file. The file format is shown in Figure 36. It is simply a header line, followed by a row and column number in the image to reference the filter. This is followed by a sequential, space separated (wavelength, radiance) list of values. The units are defined by the currently selected spectral display option (i.e., counts, radiance or reflectance) and care should be taken to make sure the units of the spectral filter being read in match those of the image to be processed. The row/column value reference is used to correct for the non-linear spectral dispersion (smile) of the instrument. The (row, column) centroid of the selected filter is also displayed in the (XF, YF) label in the filter controls box. The correction formula is stored in the image cube header, and is described in the Data Calibration section.

```
# C:\CD-Data\Software\HSAnalDoc\Data\Parking_LotI40.cube
60 385
397.06 204.41
399.72 173.39
402.38 178.61
          .
          .
          .
```

Figure 36: Spectral Filter Text File Format.

To Save a filter defined using the *Select Region* tool, use the *Write* button in the *Filter Controls* Box.

Typically these filters are defined by selecting a pixel or region of pixels from an image, as described above, and then saved to a file using the *Write* button for subsequent processing in other images. Spectral filters can be specified from other imagers or sources (e.g., data saved from other image cubes) and read in with the *Read* button. The spectral bands do not need to be the same, the code will interpolate to the spectral bands of the current cube. Filters can also be specified from a file of laboratory reflectance measurements, in the format shown above. However, the image cube data will have to be reflectance normalized first.

2.5.3 Selecting Wavelengths for Processing: Sel Wvl Button

Often the user will want to reduce the number of wavelengths used to emphasize some specific phenomenology using only a few bands. The *Spectral Average* function averages bands together to reduce the number of bands. The *SelWvl* button allows the user to select specific wavelengths for processing. Note: a spectral filter must be defined before a set of wavelengths can be selected. The code then proceeds with the spectral processing using only the wavelengths selected. Figure 37 shows the *Select Filter Wavelengths* Dialog Box. Here the user can select to use individual wavelengths, *Save* the selection as a text file, *Read* a previously defined selection, or *Reset* to the use all the wavelengths.

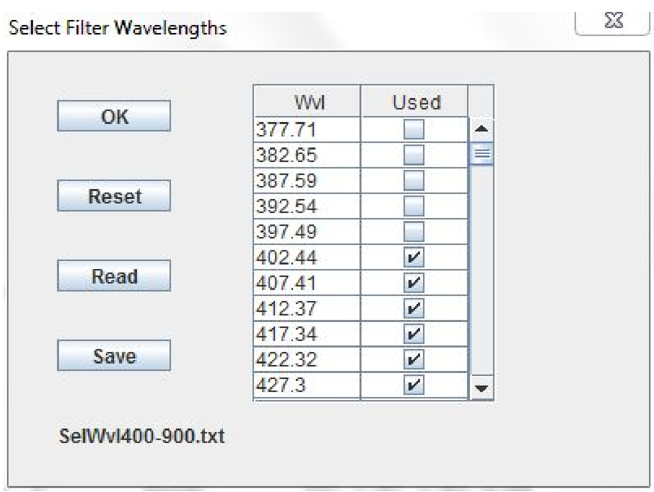


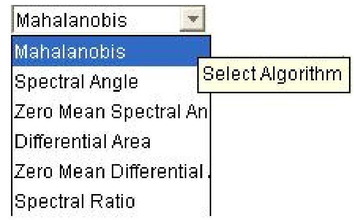
Figure 37: Select Filter Wavelengths dialog box.

2.5.4 Spectral Algorithm Selection

Given the specification of a spectral filter, an algorithm for pixel-by-pixel spectral detection must be defined. There are many possible algorithms that can be considered (and more are being developed all the time). SRAnal provides two basic types of algorithms that can be used: *statistical*, represented by the *Mahalanobis Distance*, and *vector* represented by

Spectral Angle Mapper (SAM) and its variants. The algorithm is selected using the Combo Box shown in Figure 38.

Figure 38: Spectral Algorithm Selection Combo Box Options.



The *Mahalanobis Distance* is a statistical measure of the spectral distance between a pixel and the mean of the spectral distribution defined from the spatial selection of the spectral filter (i.e., training set). The training set is used to compute the statistical spectral covariance matrix. The *Mahalanobis Distance* (squared) is defined to be the inverse of the covariance matrix, pre- and post- multiplied by the unknown pixel spectrum minus the mean spectrum of the training set,

$$D^2 = (\boldsymbol{x} - \boldsymbol{\mu})' \ S^{-1}(\boldsymbol{x} - \boldsymbol{\mu}),$$

where S is the covariance matrix of the training set, and D is the *Mahalanobis Distance* of the point $\boldsymbol{x}$ to the mean $\boldsymbol{\mu}$ of the training set distribution. <u>Note, because calculating the *Mahalanobis Distance* requires a matrix inversion, the training region selected must have at least the same number of points as spectral bands, otherwise an error message will be generated in the *Filter Controls* text label</u>.

The *Spectral Angle Mapper*, or dot product, algorithm is a very simple filtering algorithm that treats each spectral radiance as an N-dimensional vector and simply computes the angle between the two vectors by dividing the dot product of the two vectors by each vector's magnitude. Formally, this algorithm is given by

$$C_{DOT} = \frac{\sum L(\lambda_n) \bullet F(\lambda_n)}{\sqrt{\sum L(\lambda_n)^2 \bullet \sum F(\lambda_n)^2}}$$

where $L(\lambda_n)$ is the measured spectral radiance at the nth wavelength, and $F(\lambda_n)$ is the filter spectral radiance at the nth wavelength. Subtracting the mean value from both the filter and spectral radiance at each pixel provides the *Zero Mean (ZM) Spectral Angle* algorithms.

Another completely different type of vector matching algorithm can be formed by normalizing both the measured and filter radiance such that each encloses unity area, and subtracting the area "trapped" between the two curves from 1.0. For two identical spectral radiance, zero area will be "trapped", and the correlation value will be 1. As more and more area lies between the two curves, the correlation value will become smaller and smaller. This is the *Differential Area* algorithm. By subtracting the mean from each spectral radiance value and using the resultant radiance values in the above algorithm yields the *Zero-Mean (ZM) Differential Area* algorithm.

The *Spectral Ratio* algorithm computes the correlation as one minus the sum of the difference between the ratio of the radiance to the filter from the mean ratio.

<u>2.5.5 Filter Button and Color options Check Box</u>

The *Filter* button tells the software to perform the spectral correlation based on the selected algorithm and spectral filter. The result is a correlation map image, for the current threshold setting, and is displayed in the image window. The spectral correlation threshold setting is specified using the Text Box and Slide Bar shown in Figure 39.

Figure 39: Spectral Correlation Threshold Setting.

An example of a spectral correlation processing result using the *Zero Mean Differential Area* algorithm on a filter spectrum selected from natural vegetation (leaf) is shown in Figures 40 and 41, below.

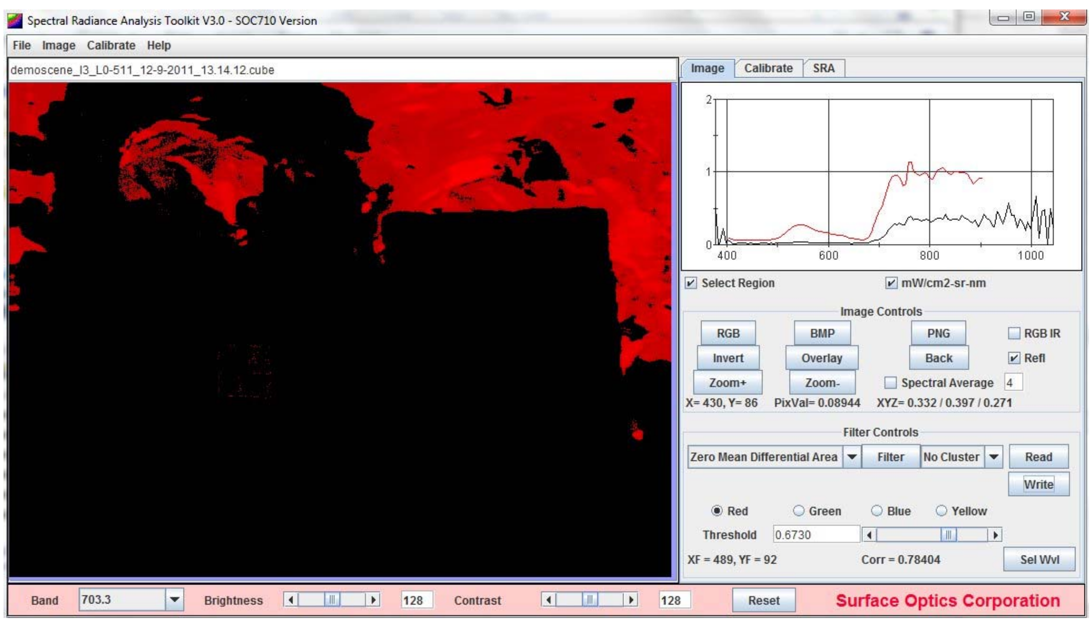


Figure 40: Spectral Correlation Results Image Display.

The image window in Figure 40 shows highlighted pixels, which are defined as a result of the spectral correlation processing, and the threshold level specified. In this case, the real plants are highlighted based on the spectral filter selection shown. The Spectral Plot display now shows the spectral radiance of the pixel pointed to in the image as well as the spectral filter function in red.

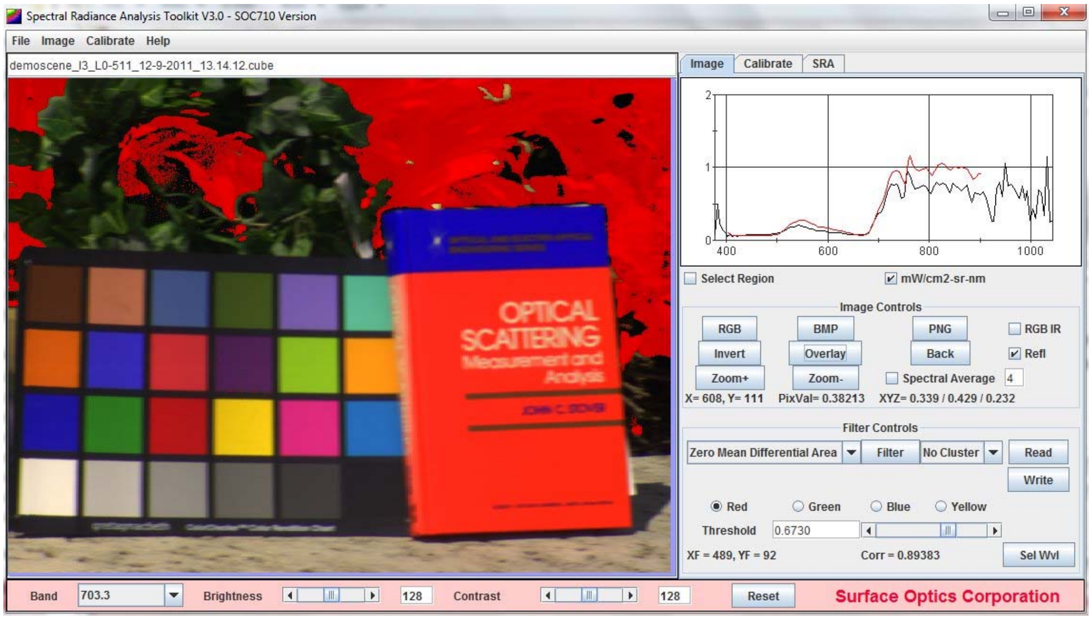


Figure 41: Spectral Correlation Map Overlaid on RGB Display.

The image window in Figure 41 shows the highlighted pixel clusters which have been *overlaid* on the RGB image. The highlighted pixels are defined as a result of the spectral correlation using the Zero Mean Differential Area Algorithm. In this case only wavelengths between 400 and 900 nm were used using the *SelWvl* option to eliminate noisy data.

2.5.6 Additional Filters: Red, Green, Blue and Yellow

It is possible to perform correlations for up to four filters using the *Red*, *Green*, *Blue* and *Yellow* radio buttons. A separate spectral filter can be assigned to each button along with a separate threshold by selecting a color and performing the steps as outlined above for processing the data.

The following is an example of using the *Blue* filter along with the *Red* filter from the example above to show multiple correlation filters. The user first selects another region of interest, in this case the artificial plants, and down selects the bands to be between 400 and 900 nm to eliminate noisy data. After selecting the color blue and applying the filter the result is shown in Figure 42.

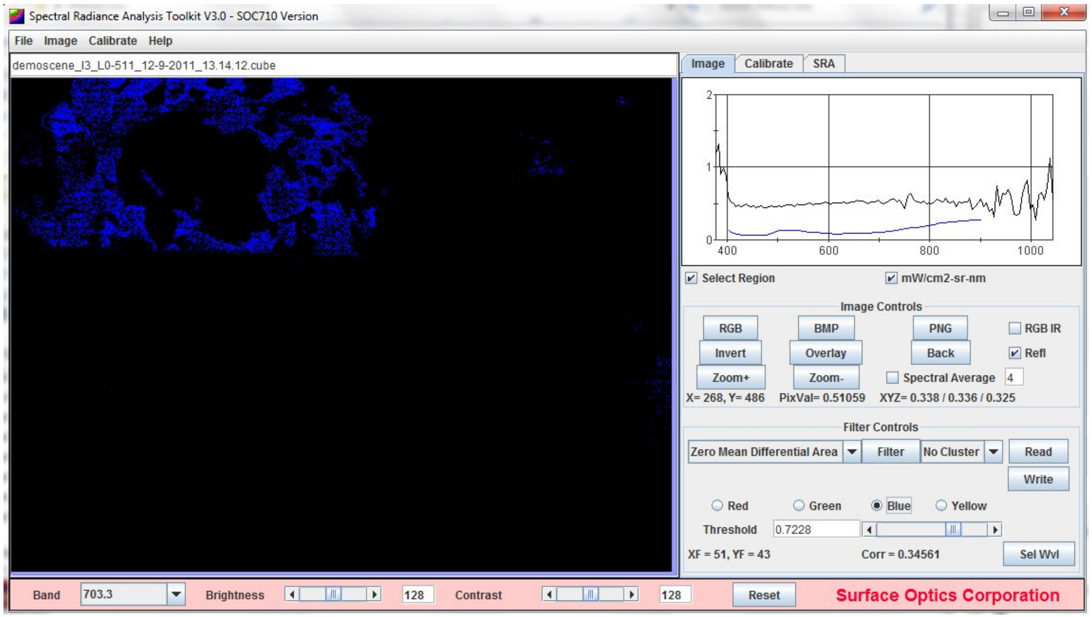


Figure 42: The Results of Mahalanobis Processing on a Spectral Filter from the Fake Leaves.

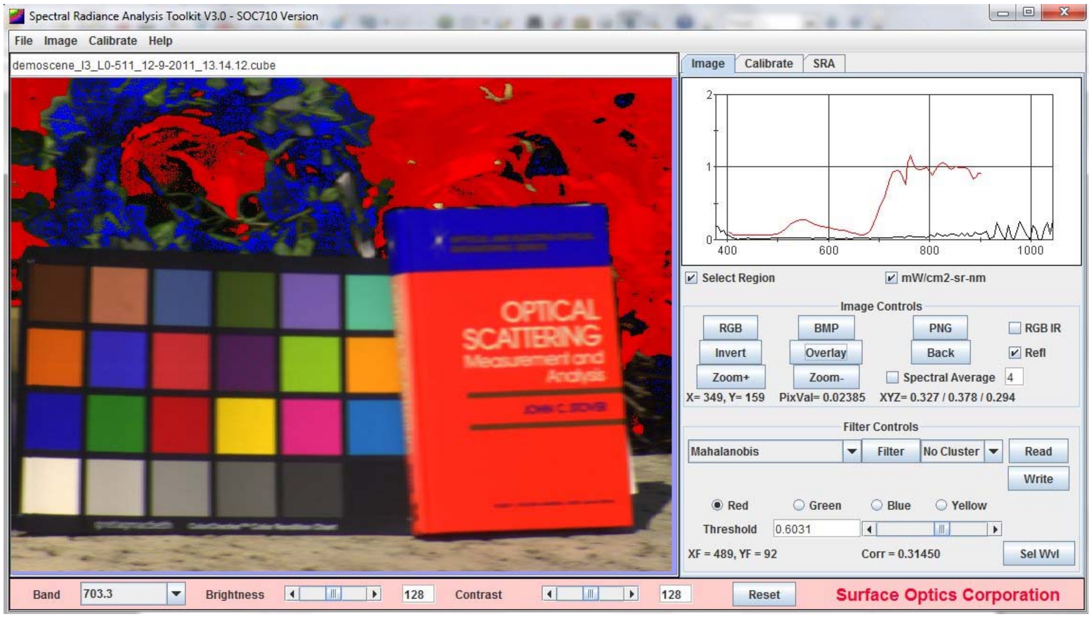


Figure 43: Overlay Results for the Red and Blue Filters.

2.5.7 Cluster Function

The *Cluster* function performs a first order spatial clustering of the image which can be used to refine a classification. Typically, any spectral classification will result in pixels which are considered *True* and *False*. *True* matches are those matches which are on the object which you are looking for in the image. *False* matches are those that are not. Fortunately, in many cases, False matches are interspersed across an image and are not concentrated spatially in any one area, while *True* matches generally are. The cluster function returns the largest spatial clustering of matches above the spectral threshold, thereby rejecting many of the *False* matches contained in a processed image. The following images show examples of the spatial clustering algorithm in use.

In the example below, a spectral filter was defined from the blue band across the top of the book. Using the Zero Mean Differential Area algorithm, Figure 44 shows the overlay of the correlation results. There are *False* matches on the light blue patch on the color panel, which is referred to as spectral clutter. The target object, the blue top on the book, shows a much higher degree of correlation, as you would expect. The Cluster function can be used to eliminate the *False*, clutter region.

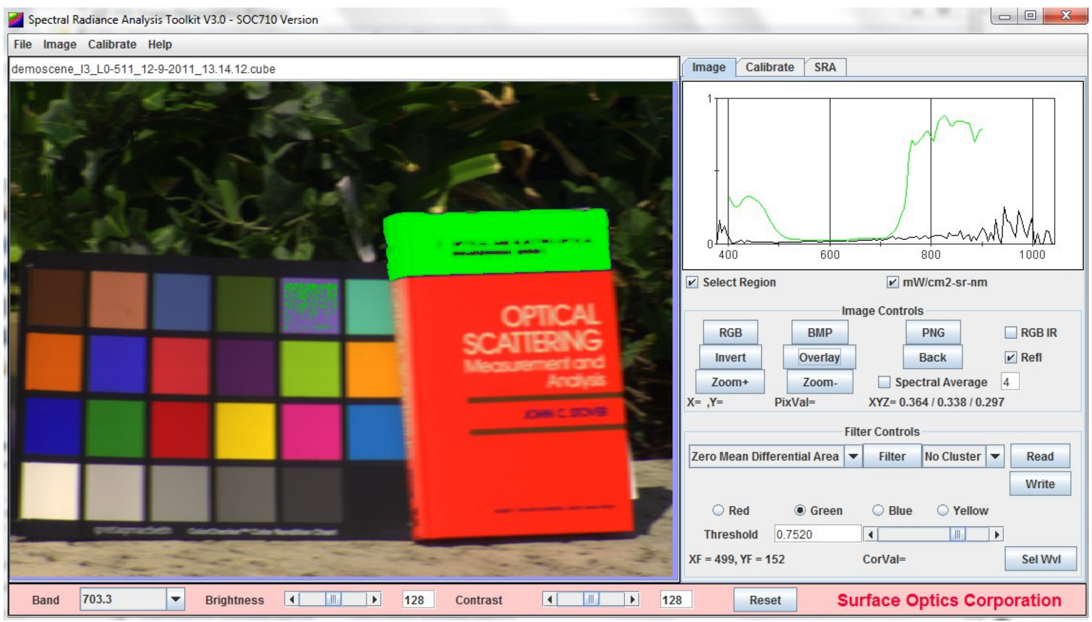


Figure 44: Result of a Spectral Correlation Showing Spectral Clutter on the Light Blue Color Patch.

By selecting the *Cluster* option in the Combo Box and clicking the filter button, the software searches for the largest spatial cluster of spectral matches which in this case is the blue band on the book. In Figure 45, the results of the spatial clustering refinement are shown, eliminating the clutter on the light blue patch.

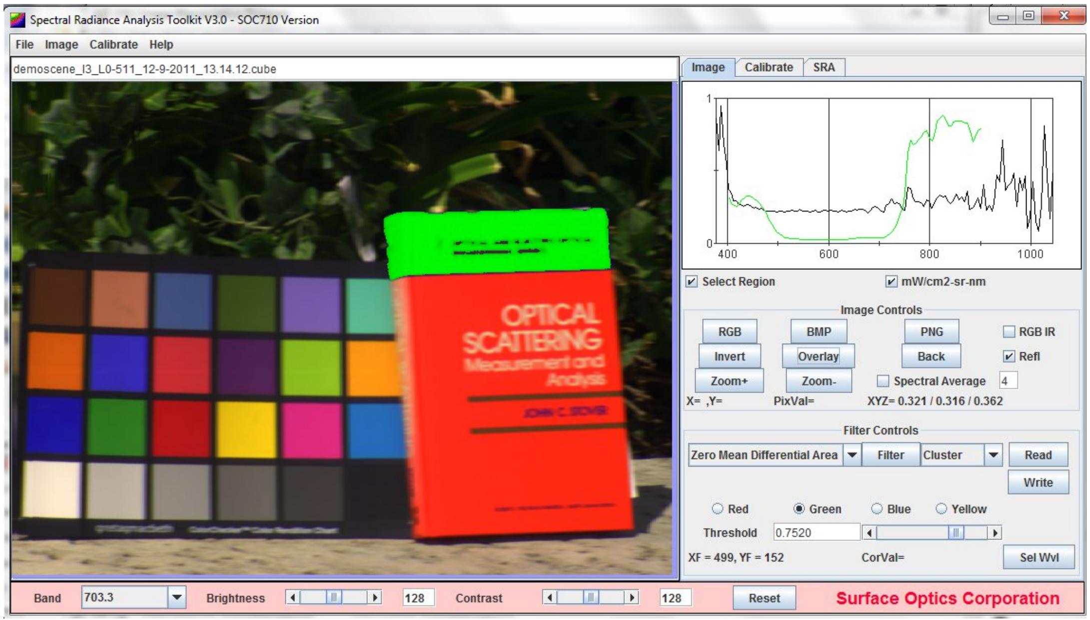


Figure 45: After Spatial Clustering.

2.6 Calibrating Images: *Calibrate* Menu/Tab

The SOC-710 system is fully calibrated at the factory and calibration files are provided with the system installation. Hyperspectral image cubes saved from the SOC 710 imager are calibrated in a three step process. The calibration steps include spectral calibration, dark level offset correction and spectral and spatial radiometric calibration. These functions are accessible through the *Calibrate* panel tab on the SRAnalysis Toolkit software, shown in Figure 46. These functions are also available on the pull down *Calibrate* menu item.

Additionally, if a material of known reflectance is in the image, such as the color panel shown in the figure, this can be used to perform a reflectance normalization correction. These steps will be described in detail, below.

The fundamental philosophy of our calibration process is to maintain the integrity of the raw data. All of the specific data introduced during calibration is stored in the image cube file header or footer. All of the calibration steps can be reversed if a wrong file is introduced, or the instrument is out of calibration, so that no raw data is lost and the image can be recalibrated using the correct files. However, a fully calibrated image cube, which cannot be un-calibrated, can be saved as four byte floats, using the *Save Float* button, for processing in other applications.

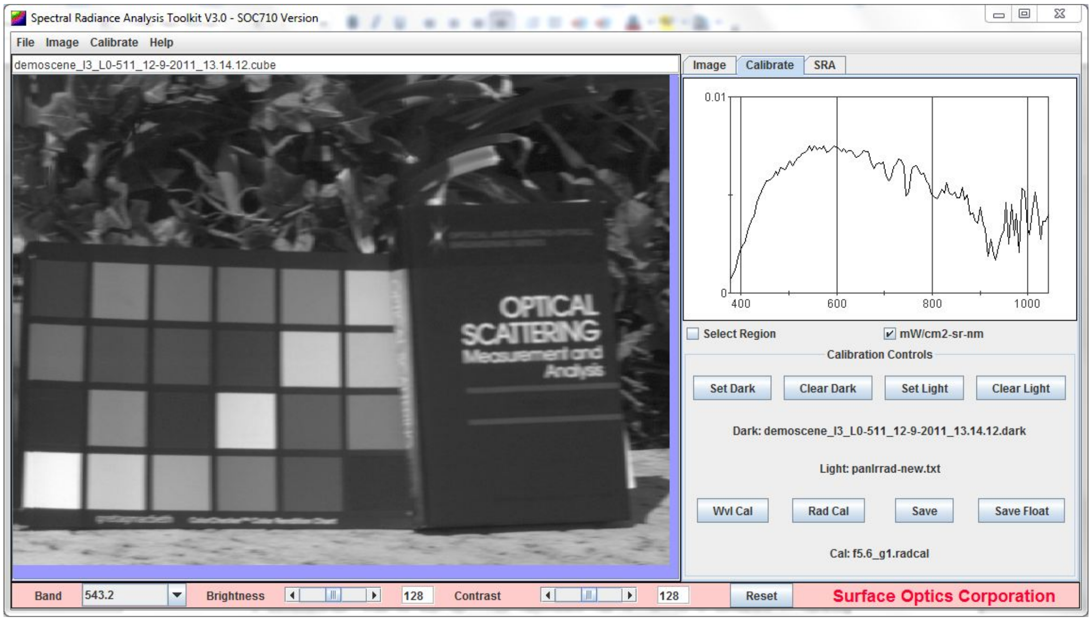


Figure 46: SRAnalysis Calibration Tab.

2.6.1 Spectral Calibration

Wavelength calibration of the SOC-710 system is performed at the factory using monochromatic light sources and the results are included in the file: DefCalLite.txt. Normally, this file is stored in the working directory for the SOC-710 system software and is automatically read on start-up. This calibration can be viewed or modified by clicking on the *WvlCal* button in the *Calibration Control Box*. Figure 47 shows the Wavelength Calibration dialog box.

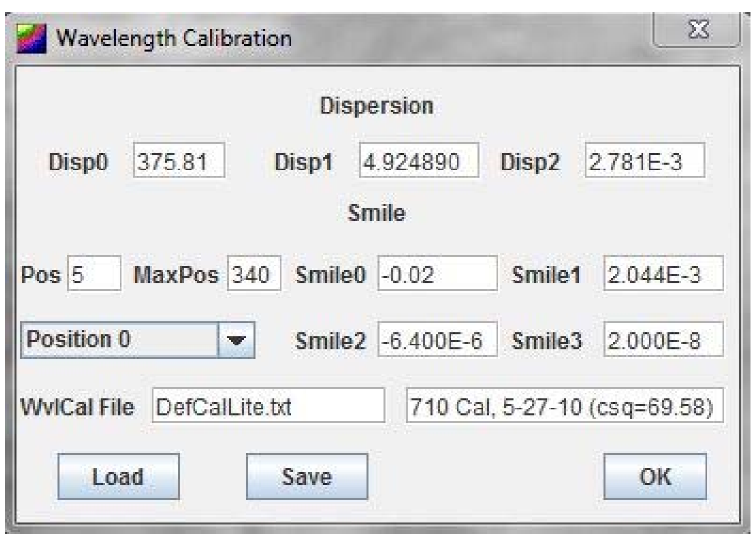


Figure 47: Wavelength Calibration Dialog Box.

The parameters, *Disp0*, *Disp1* and *Disp2* are used to calibrate the spectral dispersion of the spectrometer. *Disp0* is the first wavelength in nanometers of the data set, *Disp1* is the linear dispersion, in nanometers, per band and *Disp2* is a second order correction term.

The parameters: *Pos*, *MaxPos*, *Smile0*, *Smile1*, *Smile2* and *Smile3* are used to correct for non-linear optical distortions that affect the actual wavelength measured at a particular position on the FPA. In the spectrometer, the light from the foreoptic passes through a slit, on to the grating, which disperses the light on the FPA. Ideally, the slit images as a straight line on the FPA; in practice, optical distortions in the system bend the image of the slit into a curve. This effect is referred to as "smile."

The smile is corrected in the data using a third-order equation based on the position in the FPA. The smile parameters are fit at three positions (rows) in the array, and the values are interpolated for other positions. The smile parameters for each position can be viewed/modified using the *Position* Combo Box. The points where the smile curves are fit are given by the *Pos* parameter. The maximum row where a particular wavelength is detected is the *MaxPos* parameter. The *Smile0*, *Smile1*, *Smile2* and *Smile3* parameters are a third order equation that calculates the fractions of a pixel (row) shift (using the dispersion equation) based on the difference between the column and *MaxPos*.

The text boxes in this Wavelength Calibration window can be directly modified by the user, and the *Load* and *Save* buttons allow for updating and recalling this data. Figure 48 shows an example of the format of this file.

```
#Default Calibration file (WvlCal.txt csq=5.02)
397.06 2.656062 0.001293
 15 491 -0.01  0.00099822 -3.00E-8  1.0E-9
 55 509 -0.04  0.00111717  2.53E-6  0.0
 88 609  0.04 -0.00139172  1.00E-5 -1.0E-9
```

Figure 48: Example DefCalLite.txt.

2.6.2 Dark Level Offset Correction

The FPA and associated electronics of the imaging system produce a level of electronic noise in the image which needs to be removed. The electronic noise will be dependent on operating conditions (e.g., ambient temperature), how long the instrument has been operating and, most importantly, the integration time used in capturing the image. This dark noise data should be routinely recorded and saved at, or near, the same time as the image data collection.

The dark file is collected by physically blocking the light path to the FPA and taking and saving a small image cube (~25 lines). This file is generally stored with the same image file name with a *.drk* extension. The data is applied as an offset correction by simply clicking the *Set Dark* button and navigating to the file. The dark data can be easily removed using the *Clear Dark* button.

2.6.3 Spatial and Spectral Radiometric Calibration

The optical throughput of the system varies as a function of spatial and spectral position on the FPA. Optical effects such as vignetting (a drop in intensity along the borders of the array), the spectral response of the optics, grating dispersion element and the spectral response of the FPA itself all combine to modify the measured spectral and spatial radiances of the scene. For the SOC-710 system, the FPA is translated across the image of the spectrometer slit so that the calibration must be performed for each row and column of the system.

The gain calibration array is determined by capturing a uniform image from a known, calibrated illumination source. This is performed in the factory by capturing an image of the exit aperture of the LabSphere Uniform Source calibration sphere.

Uniformity (gain) calibration files are prepared at the factory and are provided with the system. The gain calibration is applied using the *Rad Cal* button in the Calibration box. This button opens the *Rad Cal Display* window, shown in Figure 49. The Rad Cal window has two functions, one performs "cal-ing" and "uncal-ing" (if necessary) an image during a processing session. The other allows the user to prepare their own calibration files given suitable image cubes captured from a calibrated integrating sphere, and is described elsewhere.

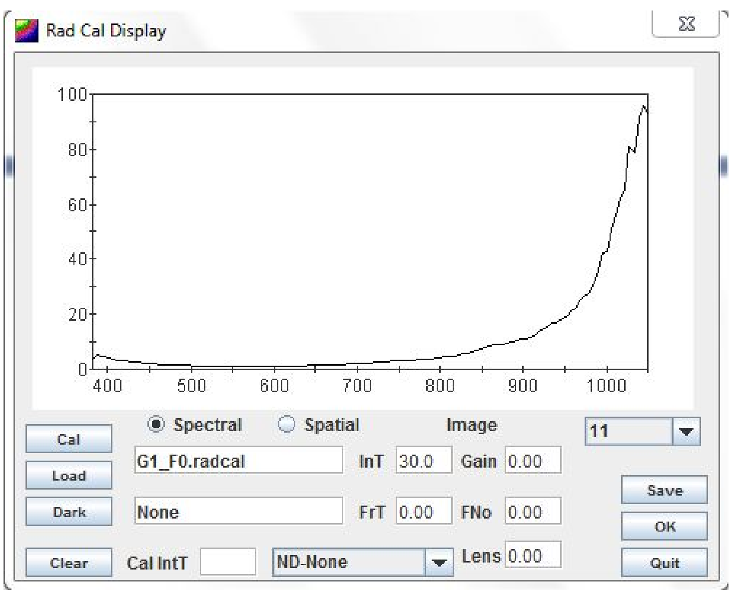


Figure 49: Spectral - Spatial Gain Calibration Window.

Gain calibration files have been measured and prepared at the factory and are stored as ".cal" files in the SOC-710 system folder. These calibration files are large (180 Mbytes) to accommodate the gain correction for each pixel row and column in the image. A copy of the appropriate gain calibration file must be stored in the same folder as the data cubes. When saving a calibrated image cube, the file name is stored in the header. Subsequent processing on the cube will read in the gain file stored with the cube data.

Figure 50 shows the Rad Cal Display window with the important buttons/information required for calibration highlighted. The simple procedure to apply this calibration correction to the image is to enter the image integration time and then press the *Cal* button in the *Rad Cal Display* window to open a dialog box for reading this data, then press the *OK* button to apply the calibration and return to the main application.

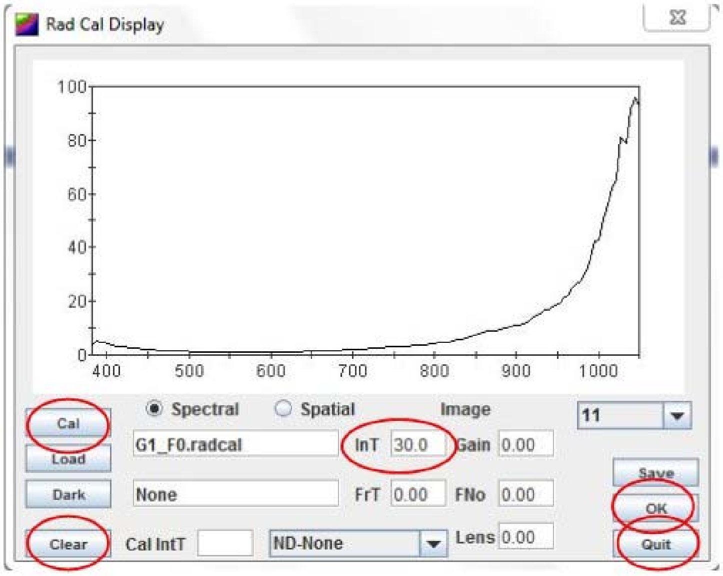


Figure 50: ***Rad Cal Display*** **Window with the Key Buttons Highlighted.**

The text boxes under the spectral display in this window record a number of parameters relevant to the imaging sensor: Integration Time (*InT*) in milliseconds is the time to capture each line in the image, Frame Time (*FrT*) in milliseconds is the time to capture a complete image frame (some number of lines), *Gain* is the gain setting on the electronics, *F/No* is the f-number of the optical system, and *Lens* is the focal length of the foreoptic. Except for the integration time (*InT*), these values are stored in the file header for information only and do not affect the gain correction. The preprocessed calibration data has been normalized by the integration time of the raw calibration image (*Cal InT*) so that reading a .cal file only requires input for the integration time of the image that is being calibrated *(IntT*). Note: The *InT* value must be specified before a .cal file can be read.

The graphic display in Figures 49 and 50 show the gain factor for each spectral point in the image. The Combo Box on the right allows the user to select the spatial column to view the gain calibration. The shape shows the spectral drop off in efficiency of the spectrometer at the long and short wavelengths, which is corrected using this gain factor.

The *Spectral* and *Spatial* radio buttons below the graph allow the user to view the gain calibration in either the spectral or spatial dimension. Figure 51 shows the graph of the gain correction plotted versus column. The Combo Box now selects the wavelength to view gain function. The slight bend in this curve is the correction of optical vignetting in the system.

The *OK* button saves the gain calibration information in the image cube header and returns to the main application. The *Clear* button resets the gain array to unity, thus “un-cal-ing” the image. The *Quit* button returns to the main application, without modifying the gain correction.

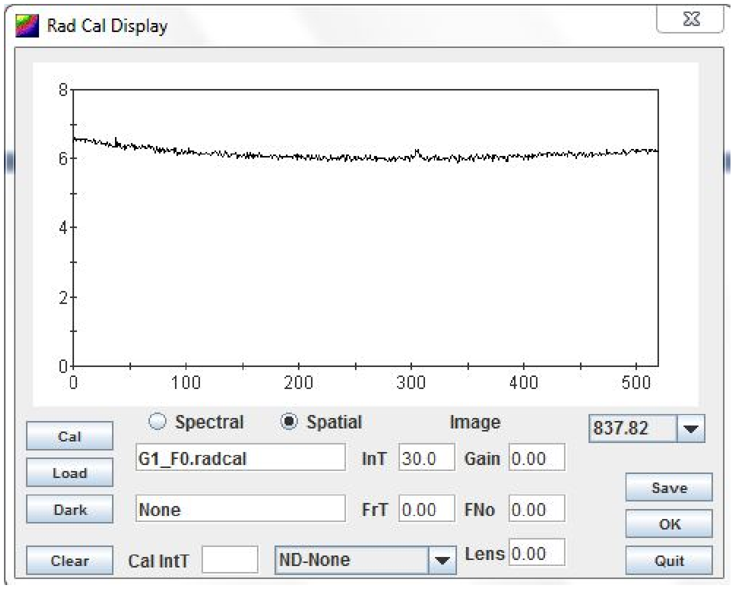


Figure 51: Spatial gain calibration display.

2.6.4 Reflectance Calibration (Normalization)

Many applications require an additional calibration step to obtain estimates of material reflectances in the image. This is an extremely complicated task to do exactly, but a simple reflectance calibration can be performed from the image data itself if a suitable material is identified in the image with known reflectance.

Starting from the simplified radiance equation for a pixel,

$$L_\lambda = R_\lambda * S_\lambda * A_\lambda * O_\lambda$$

where,

R – is the material reflectance

S – is the spectral solar irradiance

A – spectral atmospheric transmission, radiance

O – is the spectral optics transmission

and, using the measurement of the pixel radiance of the standard material, also in the image,

$$N_\lambda = R^n{}_\lambda * S_\lambda * A_\lambda * O_\lambda \quad ,$$

then, given the lab measured reflectance, $R^n{}_\lambda$, of the standard, the unknown reflectance is obtained from the ratio

$$R_\lambda = L_\lambda * R^n{}_\lambda / N_\lambda \quad .$$

Once an image has been reflectance calibrated, secondary standards can be defined in the image for subsequent image analysis without the lab standard in place.

Reading in the reflectance of the reference material used for reflectance normalization is accessible through the *Norm Reflectance* pull down menu option from the Calibrate menu. The code assumes a default 0.98 reflectance (which is essentially the lowest white square in the reference card shown in Figure 52. But any laboratory measurement can be input in the format shown in Figure 53. This is simply a header line, a line of two integers (not used) and then a space separated table of wavelength (in nanometers) and reflectance (0 to 1). The wavelengths do not have to match those of the imager since the code interpolates onto the spectral bands of the imager. The reflectance data must be read in for each cube processed because the code reverts to the default value when opening a new image cube.

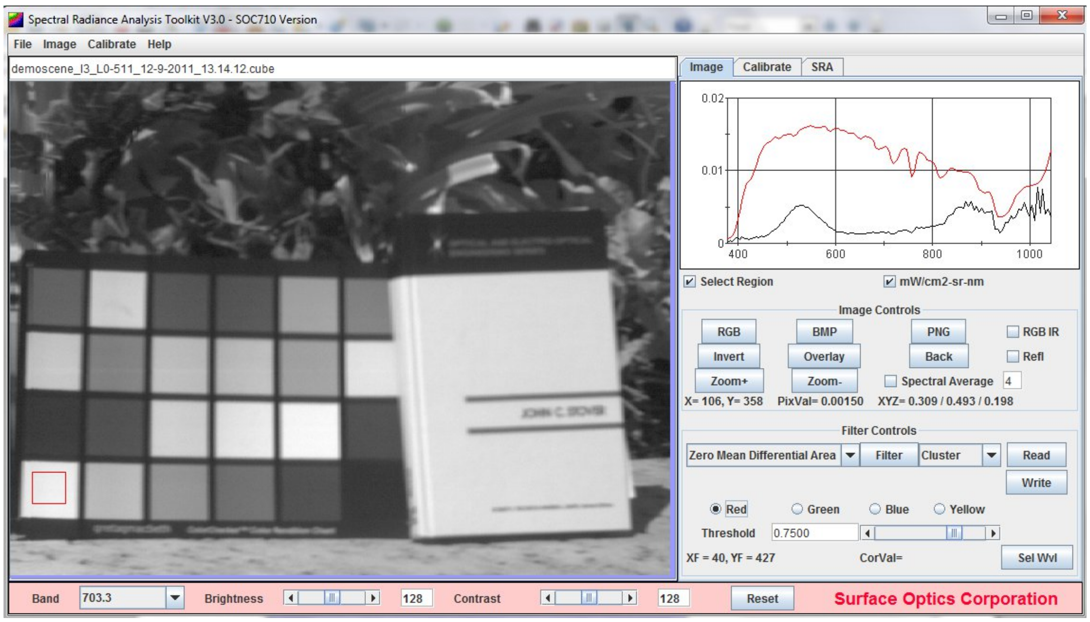


Figure 52: Calibration using Normalization Function.

Given the reflectance of the reference material has been identified, an averaged calibrated radiance spectrum of this material must be recorded and saved. This is done using the filter controls on the *Image* tab. First the *Select Region* check box must be checked. Then dragging the mouse over the reference material will average the radiance in the box and provide an estimate of N_λ, as shown in Figure 52. Save this as a text file using the *Write* button in the Filter controls. Finally, read this file in using the *Get Light* button on the calibrate tab or through the pull down menu controls. Now the *Refl* check box on the *Image* controls tab allows the user to toggle between reflectance and radiance display mode. Figure 54 shows the RGB image of the scene in reflectance mode. This procedure can be reversed using the *Clear Light* button.

```
# White Reference Material reflectance
  0  0
403.55   0.977874
408.57   0.987298
413.58   0.984065
418.60   0.983595
423.63   0.982206
428.66   0.986709
433.70   0.983718
438.74   0.985206
443.78   0.984265
448.83   0.984847
453.89   0.984596
458.95   0.985571
464.01   0.984767
469.08   0.983647
474.15   0.983972
479.23   0.984761
484.32   0.983890
489.40   0.984848
494.50   0.982815
499.60   0.983556
504.70   0.983542
509.81   0.984575
514.92   0.984468
520.04   0.984243
525.16   0.983483
530.29   0.981219
535.42   0.982662
540.55   0.985224
545.69   0.984219
550.84   0.984090
555.99   0.982929
561.15   0.982889
```

Figure 53: Example of Format of Norm Reflectance Data used in Reflectance Calibration.

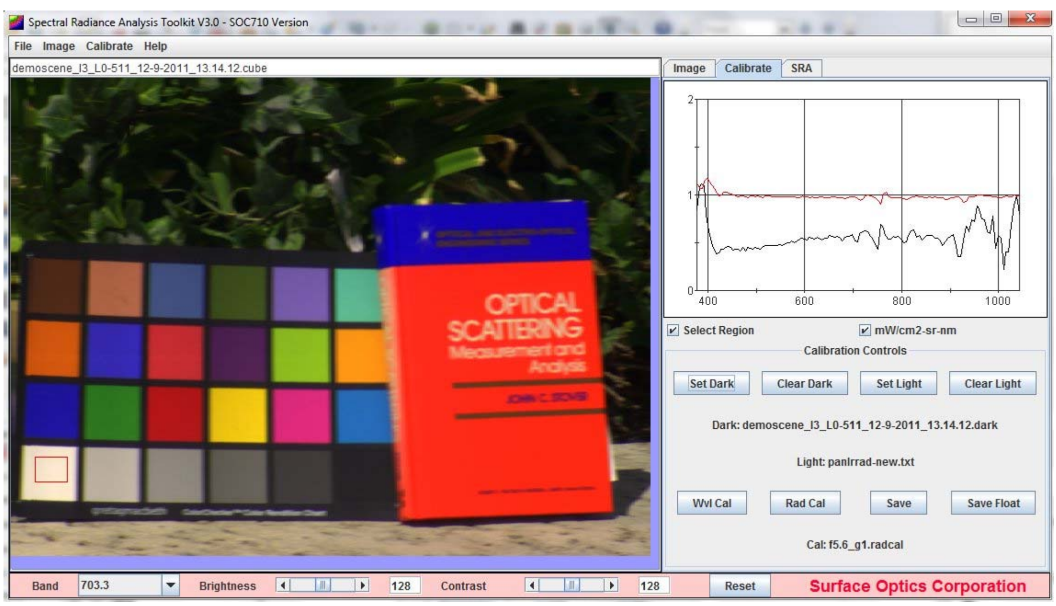


Figure 54: Reflectance Calibrated Image.

2.6.5 Calibration Procedures: Producing the Cal Files

The SOC-710 is fully calibrated before delivery, and can be returned to SOC for recalibration. Some users with the proper calibration sources and standards might prefer to perform this procedure themselves. The SRAnal software has the capability to process the calibration data to produce the spectral and radiometric calibration files.

2.6.6 Wavelength Calibration Procedure

The procedure for calculating the spectral dispersion of the SOC-710 starts with taking a sequence of spectral images from a nearly monochromatic light source. At the factory, this is performed using an ISA monochrometer, which has been separately calibrated using Oriel calibrated arc lamp sources. Figure 55 shows a calibration image recorded when the monochrometer was set to pass 550 nm light.

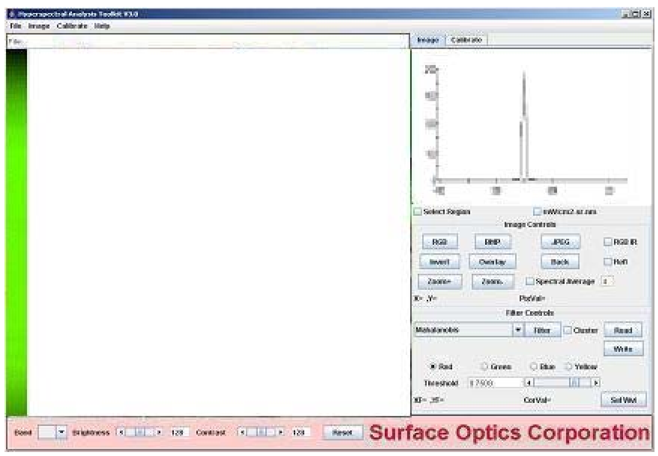


Figure 55: A Wavelength Calibration Data Set Example.

The *Avg Image* menu item in the *Calibration Menu* was used to average multiple columns of this uniform image to increase the signal to noise. Using the right mouse button to click on a pixel in the image brings up the *Spectrum Display/Fit* window, shown in Figure 56, which has a set of tools for performing the wavelength calibration.

Note: the *Select Region* check box must be unchecked to bring up the *Spectrum Display/Fit* window.

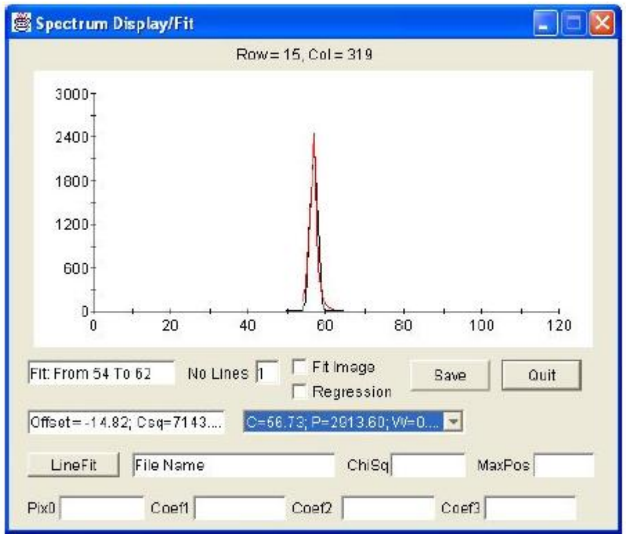


Figure 56: Spectrum Display/Fit Tools.

The plot in the *Spectrum Display/Fit* window is the raw data for the image row and column displayed at the top of the window. Dragging the mouse (holding down the left mouse button) across the plot display selects a number of spectral points that are used to fit single (or multiple) Lorentzian lines to the data. The number of lines fit is defined in the *No Lines* text box. The text box to the left of the *No Lines* display indicates the fit range. The fit results are indicated in the text and combo boxes immediately below the *No Lines* display.

The algorithm goes through the fit range and selects the *No Lines* largest peaks as starting points and uses a Levenberg-Marquardt non-linear technique to obtain a best fit to the data. The purpose is to estimate the position of the peak center, which generally doesn't fall on a particular pixel. The combo box lists the peak center (*C*), peak strength (*P*) and width (*W*) parameters for each line fit. The red curve shows the fit results for the selected range plotted and compared to the data.

This data is manually recorded as a series of wavelengths and peak center positions and saved in a separate file. An example of this data is shown in Figure 57.

410	4.5
420	8.5
430	12.5
440	16.4
450	19.7
500	38.4
550	56.7
600	73.5
650	91.4
700	108.4

Figure 57: Example Wavelength Calibration Data.

The *LineFit* button opens a File Dialog Box for reading this data. The code then performs a linear least squares fit to a second order equation to define the dispersion parameters for the system. The results are displayed in the Text boxes labeled: *Pix0*, *Coef1* and *Coef2*, shown in Figure 58, which are in fact the *Disp0*, *Disp1* and *Disp2* dispersion parameters. The wavelength at each pixel position, *P*, is then given by

$$\lambda = Disp0 + Disp1 * P + Disp2 * P^2$$

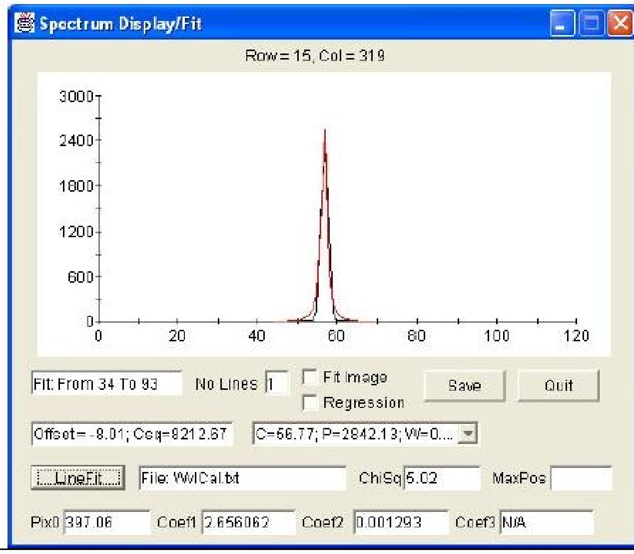


Figure 58: Dispersion Fit Results.

2.6.7 Smile Calibration Procedure

Because of the non-linear optical effects in the system, known as “smile,” the dispersion equation defined above is not correct for all spatial positions (columns) in the image. Ideally, a dispersion equation would be defined for each of the 524 columns in the image. This is not practical, however, and the approach is to fit a third order equation to the measured “smile” displacement and correct the measured wavelengths on the fly. The equation used to fit the smile calculates the shifted pixel position, *Ps*, used in the dispersion equation as a function of column position, *C*, in the array.

$$P_S = P + Smile0 + Smile1 * k + Smile2 * k^2 + Smile3 * k^3$$

where, $k = | MaxPos - C |$.

Figure 59 shows the Lorentz line fit to the 546 nm line from a calibrated Hg-Ar lamp source imaged from the integrating sphere. An integrating sphere must be used for this calibration step to insure that all pixels are uniformly illuminated.

Checking the *Fit Image* check box in the window performs this fit for each column in the image. The graphic display, shown in Figure 53, changes from a spectral plot to a spatial plot showing the pixel shift as a function of the absolute value of the difference between the maximum peak position and the peak position obtained for each column in the image.

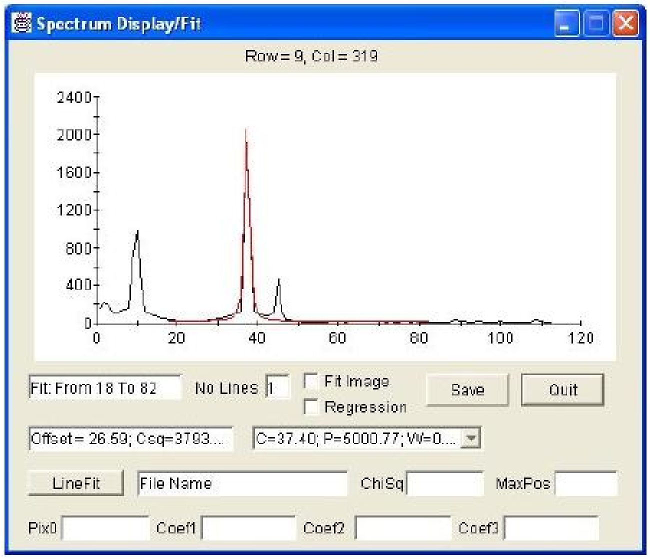


Figure 59: The 546 nm Line from the Hg-Ar Lamp Source used for the Smile Calibration.

The shape of the shift of the peak position as a function of image column shown in Figure 60 is a graphic illustration of the "smile" of the imaging system. Checking the *Regression* check box performs a linear least squares fit of the third order equation to this data.

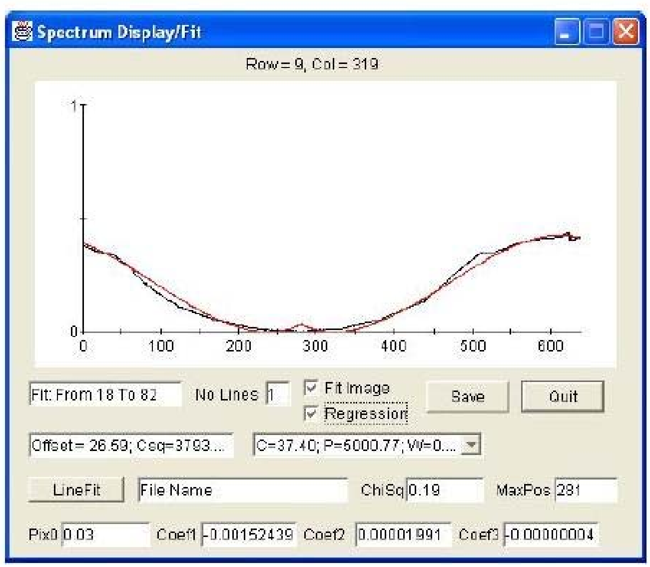


Figure 60: Smile Correction Curve Fit.

The results of the fit are shown as the red curve in the graphic display and the parameters listed in the text boxes along the bottom of the window: *Pix0*, *Coef1*, *Coef2* and *Coef3* are identified as *Smile0*, *Smile1*, *Smile2* and *Smile3*, respectively.

Because the “smile” can change as a function of position on the array, this procedure is repeated for a number of incident wavelengths (i.e., spectral positions) on the array. At present, the “smile” is fit at three positions (rows) in the array, chosen by input wavelength, and the smile parameters are interpolated for the other positions. The smile parameters are chosen based on the quality of the fit and consistency for interpolation (i.e., no wild changes in the parameters from position to position).

2.6.8 Uniformity (Gain) Calibration File

The optical throughput of the system varies as a function of spatial and spectral position on the FPA. Optical effects such as vignetting (a drop in intensity along the borders of the array), the spectral response of the optics, grating dispersion element and the spectral response of the FPA itself all combine to modify the measured spectral and spatial radiances of the scene. The RGB image of an uncalibrated data cube, shown in Figure 61, has a distinct yellow cast to it due to the non-uniform spectral response of the system.

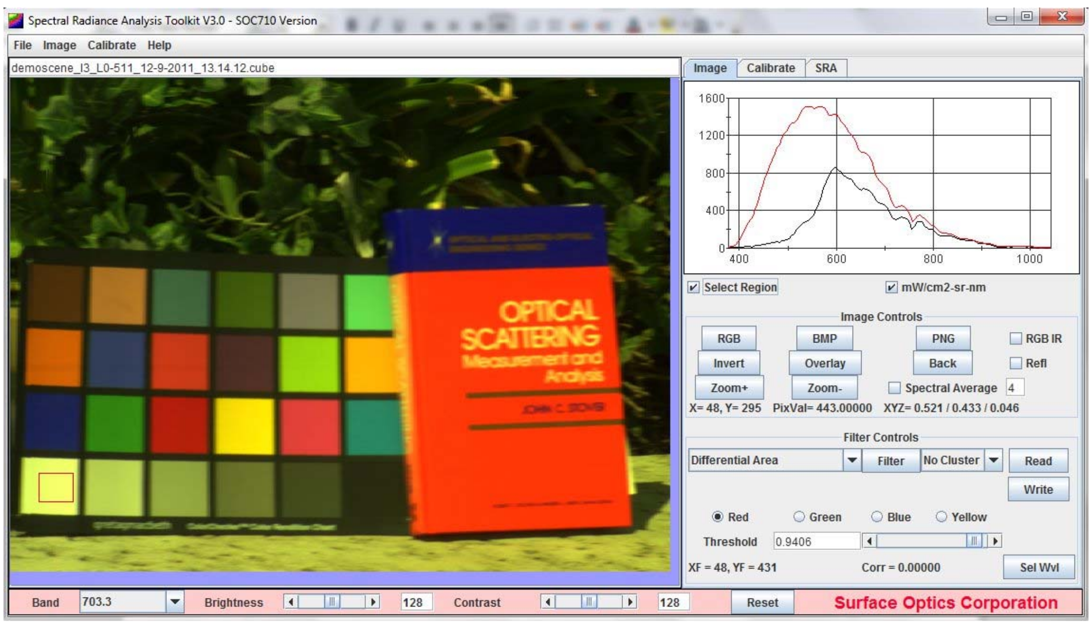


Figure 61: RGB Image Without Uniformity Calibration.

The gain calibration array is determined by capturing a uniform image from a known, calibrated illumination source. This is performed by capturing an image of the exit aperture of the LabSphere uniform source calibration sphere.

The text boxes, in Figure 62, under the spectral display in this window record a number of parameters relevant to the imaging sensor: Integration Time (*InT*) in milliseconds is the time to capture each line in the image, Frame Time (*FrT*) in milliseconds is the time to capture a complete image frame (some number of lines), *Gain* is the gain setting on the electronics, *F/No* is the f-number of the optical system (typically fixed at F/2.8 for the SOC-710 system) and *Lens* is the focal length of the foreoptic (typically fixed at 70 mm for the SOC-710 system). Except for the integration time (*InT*), these values are stored in the file header for information only and do not affect the gain correction.

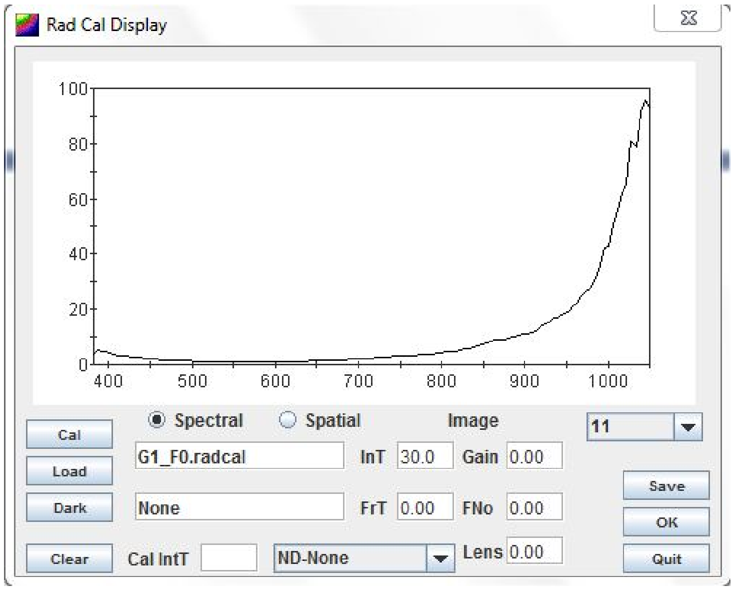


Figure 62: Spectral Gain Calibration Display.

The other significant data item required to perform the calibration is the integration time of the calibration image, *Cal IntT*, in milliseconds. The radiometric calibration is based on the ratio of the integration time for the response to the known spectral source radiance to the integration time used for the unknown radiance of the image cube.

The preprocessed calibration data has been normalized by the integration time of the raw calibration image (*Cal InT*) so that reading a .cal file only requires input for the integration time of the image that is being calibrated *(IntT*). Note: The *InT* value must be specified before a .cal file can be read.

The graphic display in Figure 62 shows the gain factor for each spectral point in the image. The Combo Box on the right allows the user to select the spatial column to view the gain calibration. The shape shows the spectral drop off in efficiency of the spectrometer at the long and short wavelengths, which is corrected using this gain factor.

The *Spectral* and *Spatial* radio buttons below the graph allow the user to view the gain calibration in either the spectral or spatial dimension. Figure 63 shows the graph of the gain correction plotted versus column. The Combo Box now selects the wavelength to view gain function. The slight bend in this curve is the correction of optical vignetting in the system.

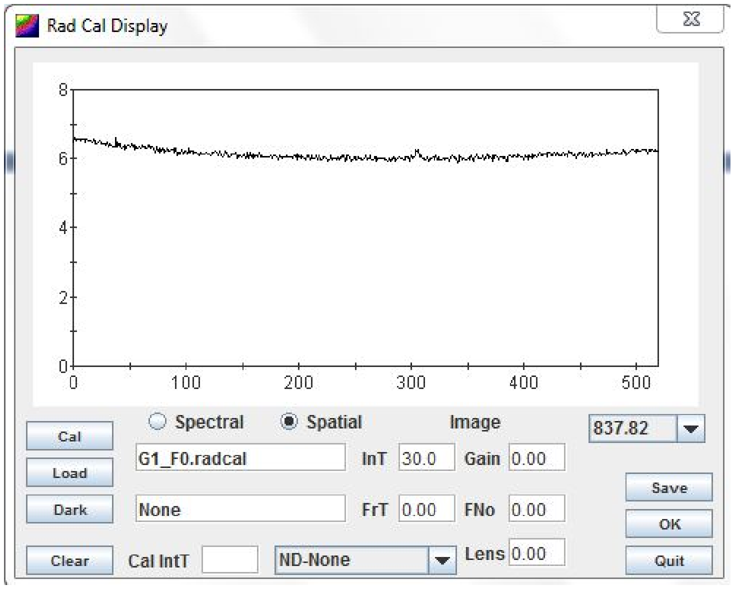


Figure 63: Spatial Gain Calibration Display.

The raw calibration images from the integrating sphere have to be processed first to produce a gain array that can be applied to the data. This is accomplished using the various command buttons, text and combo boxes in the *Rad Cal Display* window.

The *Dark* button reads in the dark image to compute the offsets for the calibration image. The dark image for the calibration data must be read as the first step in preparing the calibration gain array.

The *Load* button reads in the raw calibration image. Both the integration time for the calibration data (*Cal InT*) and the integration time for the image data (*InT*) must be specified first so the proper radiometric correction can be applied. The *Save* button saves the calibration gain array to a file for subsequent application to image data.

Generally, the intensity of the integrating sphere is high enough to saturate the FPA, even for short integration times, so a neutral density filter must be applied. The neutral density filter introduces its own spectral features into the calibration image and must be removed. This is performed using the Combo Box at the bottom of the window, which selects the appropriate neutral density correction for the data.

Currently, both the LabSphere source function and the neutral density filter correction factors are hard-wired in the code based on the hardware configuration used to collect the calibration data at the factory (Surface Optics Corporation). Modification of these spectral source and filter functions for a different hardware configuration is possible by contacting Surface Optics Corporation. A future version of the code will provide the user with a set of tools to modify this data for different calibration hardware configurations.

2.7 Spectral Radiance Analysis (*Sra*) Tab

The final tabbed panel of the SRAnal program provides simplified Spectral Radiance Analysis (*SRA*) calculations. Figure 64 shows this tab for an image taken of the exit port of a calibrated integrating sphere.

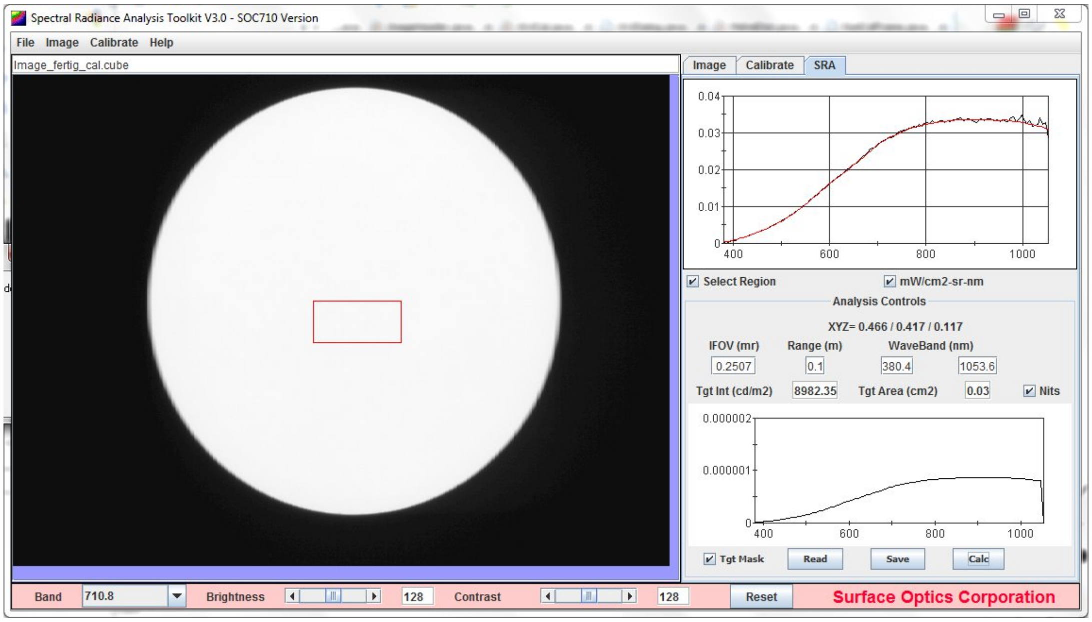


Figure 64: Spectral Radiance Analysis (*SRA*) functions.

The calculation is provided for both radiometric units, Radiant Intensity (W/sr) or photometry units (Candella per square meter, or *nits*) using the *Nits* check box. The spectral plot shows the Spectral Radiant Intensity (W/Sr-nm).

The basis for this calculation requires the definition of a target area, which is computed using the known imager Instantaneous Field of View (*IFOV*) in milliradians for each pixel, the distance from the camera to the target (*Range*) in meters, and the definition of the target pixels. The target is defined using the same *Select Region* tool described in selecting spectral filters. In this case the *Target Mask* check box must be selected as well. Targets can then be *Saved* and *Read* for subsequent processing.

The user can also select a *WaveBand* within the spectral band of the system for the calculation. The *Calc* button then performs the calculation. The *XYZ* again displays the calculation of the tristimulus coordinates for the radiance or defined illuminant (using reflectance units), as was described earlier, and averaged over the area defined by the target mask.

NOTES

11555 Rancho Bernardo Road
San Diego, CA 92127-1441
Phone (858) 675-7404
Fax (858) 675-2028
www.surfaceoptics.com