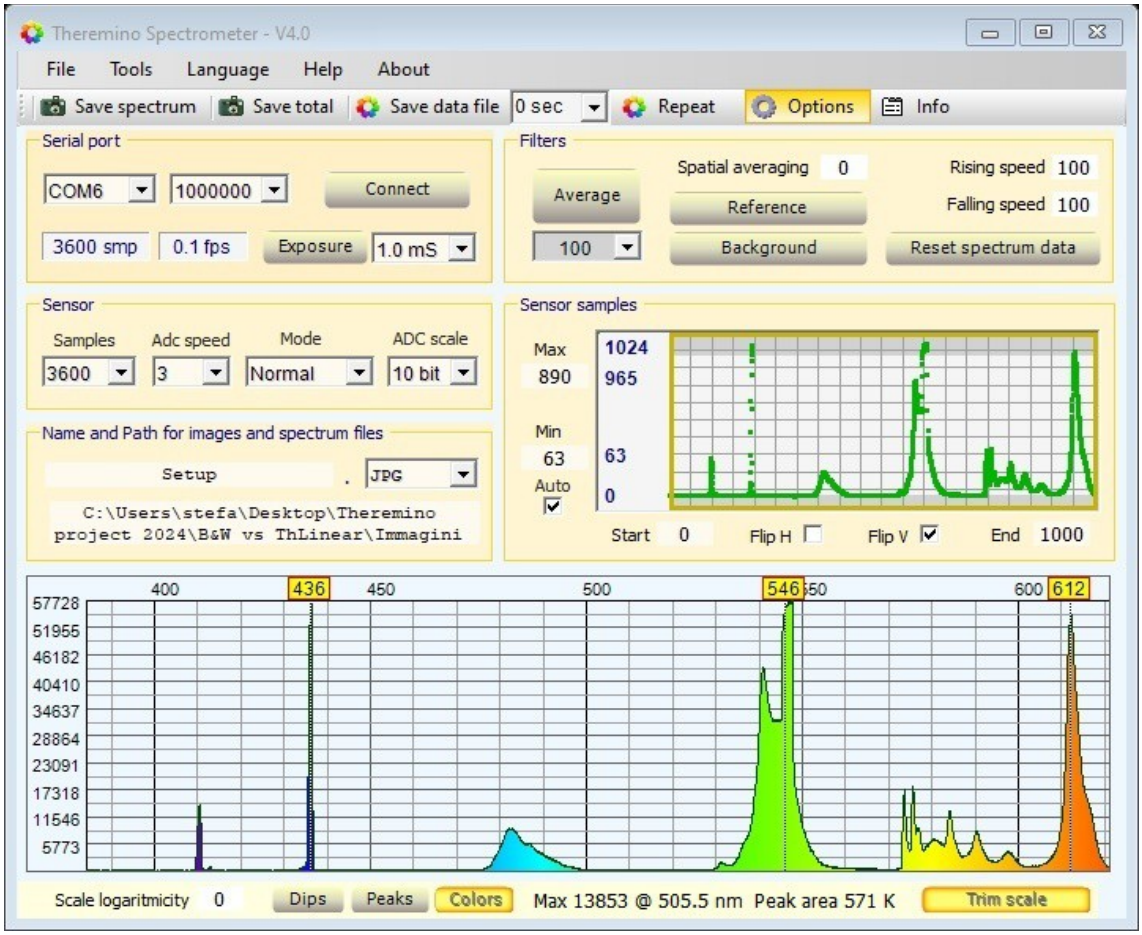
theremino **system**

Theremino Spectrometer V5.x

Instructions

Theremino Spectrometer



This application is specially written to extract thebest possible features from a spectrometer based on WebCam or Toshiba TCD1304DG and TCD1254 sensors.

If the mechanical construction is accurate, you can obtain characteristics comparable to instruments costing a few thousand euros, but with a ridiculous expense, around twenty euros or even less.

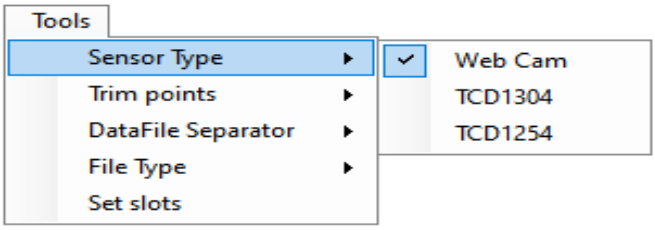
This class of spectrometers has the following characteristics:

- Measurements of wavelengths only and not of quantities of light. It is not possible to measure the quantity of light, but only to appreciate the differences in a relative and approximate way.
- The measures of light intensity are **always relative, not absolute**. Whether using a WebCam or with linear sensors, the instrument cannot measure milliwatts of light, or lumens, or lux or other similar units of measurement (see next page).
- Even the most expensive spectrometers do not have a calibrated vertical scale. Only by going towards tens of thousands of euros can you find instruments with calibrated light intensity.
- Resolution and nonlinearities caused by the grating and lenses limit accuracy to about a nanometer or so.

You might think that these are defects of our device and that more expensive devices do not have them, so on the next page you can read what Ocean Optics writes about them.

Webcams or Toshiba sensors?

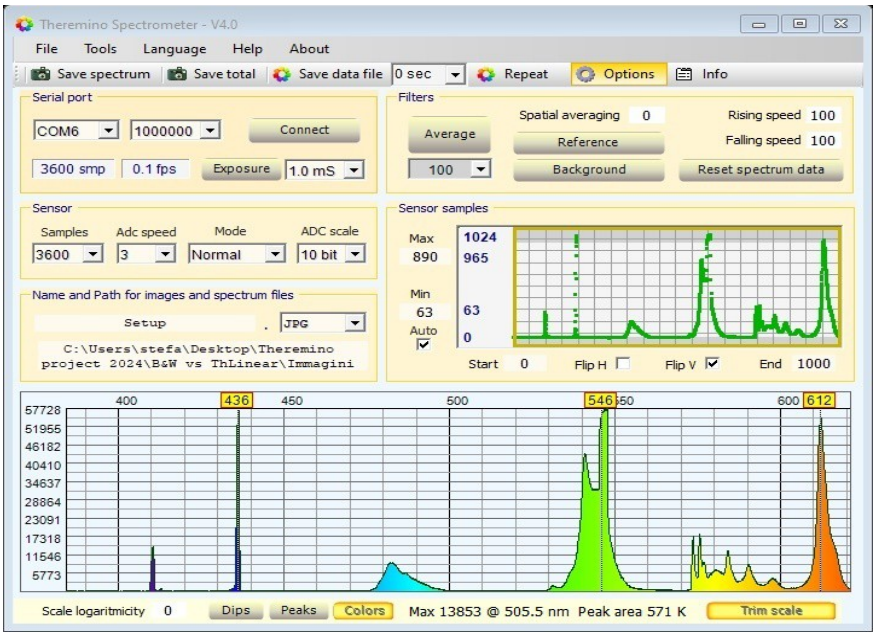
From version 4 onwards we have added the possibility to choose between two types of linear sensors (to be connected via a Nano module with our firmware) or the classic WebCams connected via USB.



Some WebCams (such as the ToupTek Astro GPCMOS02000KMA)
They work better than linear sensors, they have a very wide exposure range,
from 100 microseconds up to 1000 seconds, and are significantly easier to calibrate.

We have added the ability to use sensors ***for those who have recovery benches*** B&W or Ocean Optics ***and knows how to calibrate them***, but in all other cases we recommend good WebCams.

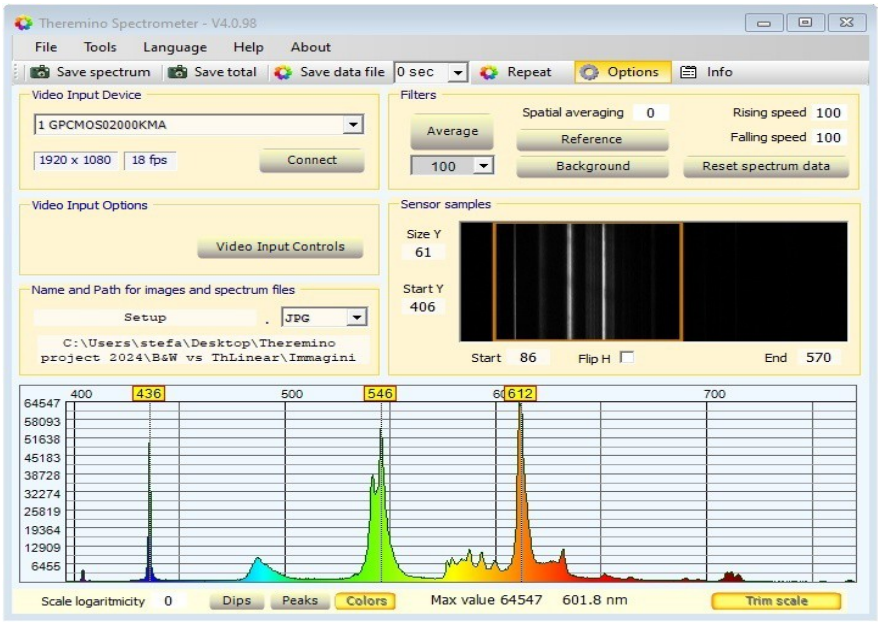
This image shows what the application looks like when connected to a Toshiba linear sensor type TCD1304 or TCD1254.



And this is what the application looks like when connected to a WebCam.

Aside from a few minor differences, most of the commands are similar and are used in the same way.

So once you have learned how to use the controls you can switch from one operating mode to another without too much difficulty.



Relative or absolute measures

Relative measures: These are the most common, where the light intensity of a sample is compared with that of a known standard or reference. This is typical in photospectrometers for UV-Vis, IR spectroscopy, etc.

Absolute measurements: In this case, the photospectrometer is calibrated so that it can directly provide a measurement of the absolute intensity of the light. To obtain absolute measurements, a very careful calibration of the instrument is required, which may include the use of calibrated standard light sources or detectors with known sensitivity.

Characteristics of Spectrometers

Taken from:***OceanOptics Glossary***

Relative Measures: Most spectrometers are used for relative analysis, where the spectral intensity of a sample is compared to that of a blank or known reference. This type of analysis is common in UV-Vis spectroscopy, fluorescence, and other similar techniques.

Calibration for Absolute Measurements: Although Ocean Optics spectrometers are primarily used for relative measurements, absolute measurements can be made with these instruments if they are properly calibrated. Absolute calibration requires the use of calibrated light standards and specific procedures to establish the relationship between the spectrometer detector response and the absolute light intensity.

Accessories and Software: Ocean Optics offers accessories and software to facilitate absolute calibration, such as calibration lamps and software modules that allow corrections to be made to obtain absolute intensity measurements. However, These operations require a level of preparation and additional equipment.

Instrument response function(IRF)

Every Ocean Optics spectrometer has what is called an Instrument Response Function, or IRF. The IRF characterizes how the spectrometer responds to light across its entire wavelength range.

This response is far from uniform.: a spectrometer will produce a different response (here defined as the number of Quick View mode counts produced for a fixed number of photons) at each pixel.

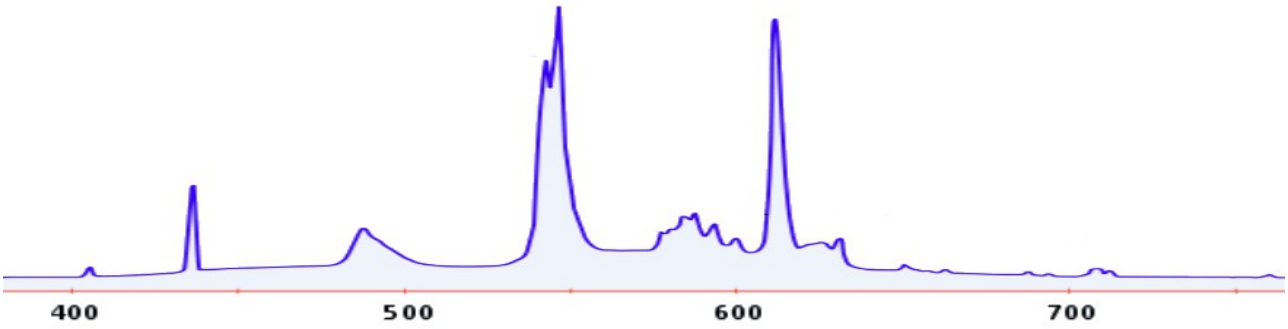
The IRF is not uniform due to the cumulative effects of optical inefficiencies in the light path. These include, but are not limited to, the following wavelength-dependent effects: attenuation of light in the fiber optic cable; absorbance of light by mirrors; grating efficiency; and detector response.

The IRF for each spectrometer is unique and cannot be truly measured. However, it is possible to compensate for the IRF. The two common corrections are relative irradiance and absolute irradiance calculations.

The calibration in question, although theoretically feasible,
would prove extremely complex in practice
with prohibitive costs, due to the purchase of numerous calibration sources
or for comparison with even more expensive instruments.

Performance

With good construction, you can obtain graphs similar to and even better than those of medium-class professional spectrometers (a few thousand Euros).



Spectrum of a fluorescent lamp obtained with a professional device (an "Ocean Optics HR2000 High-resolution Fiber Optic Spectrometer" which costs about $1200, those interested can find them used on eBay for about $300)

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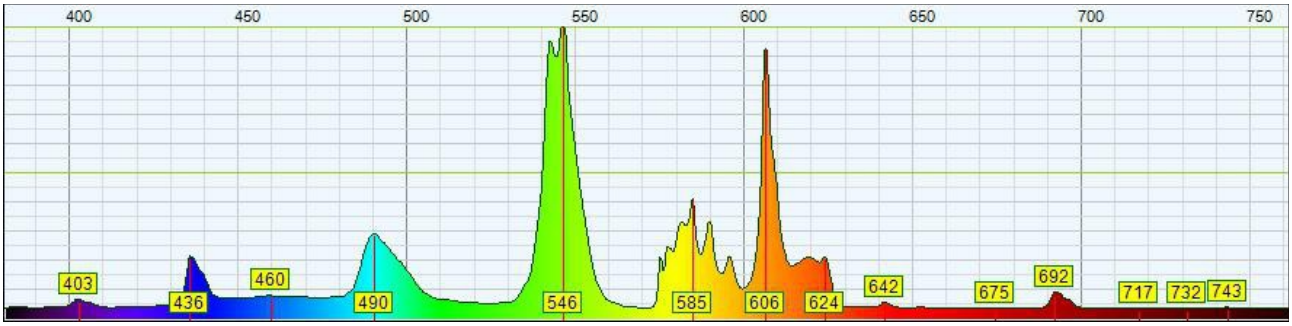
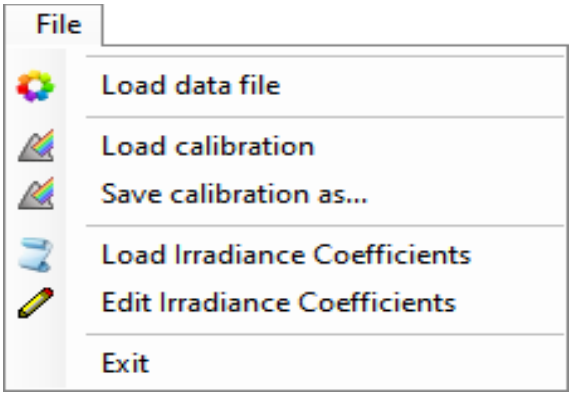
Spectrum of a fluorescent lamp obtained with Theremino Spectrometer



If the optics are well built, the dynamics and resolution are comparable if not superior.
to devices costing a few thousand Euros and our software is better than other similar ones.

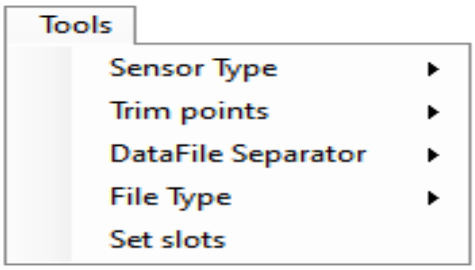
Menu Commands - Part 1



"Load data file" allows you to load previously saved spectra files. Loading and saving calibrations is explained in Appendix 1

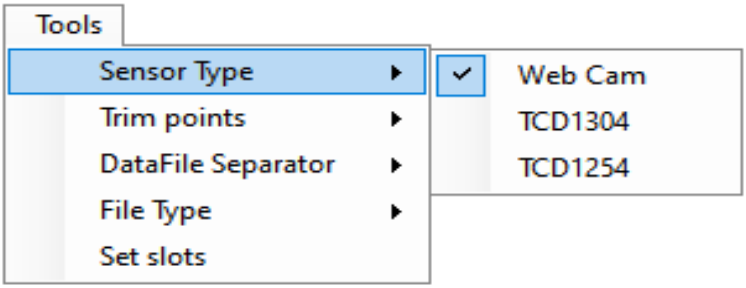
"Load irradiance coeffs" allows you to load Irradiance coefficient files. Irradiance coefficient files are explained in Appendix 7

"Exit" closes the application.

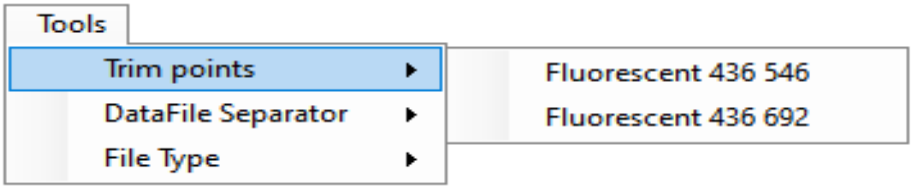


This is the tools menu which from version 4 onwards also contains the possibility to change sensor type.

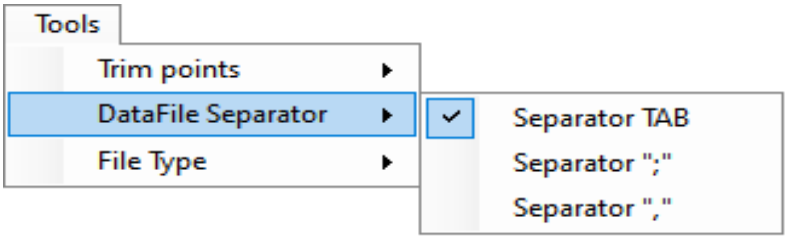
The last item "Set slots" is used to set the slots for external commands. See "Appendix 4" at the end of this document.



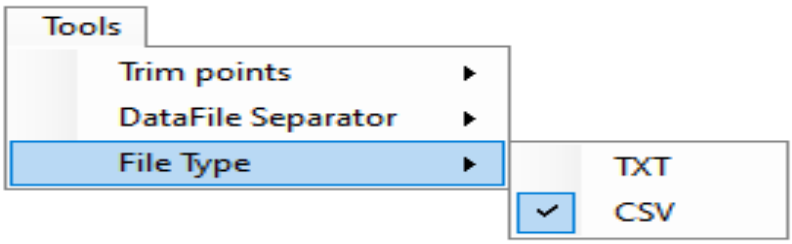
Setting the sensor type, which can be a WebCam connected directly to USB, or a linear sensor that connects via a Nano module.



Setting the standard calibration and alternative calibration.



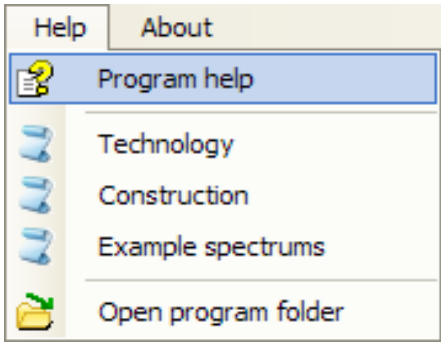
Separator character to be used in spectra data files.



File type to use for saving spectra data files.

Menu Commands - Part 2

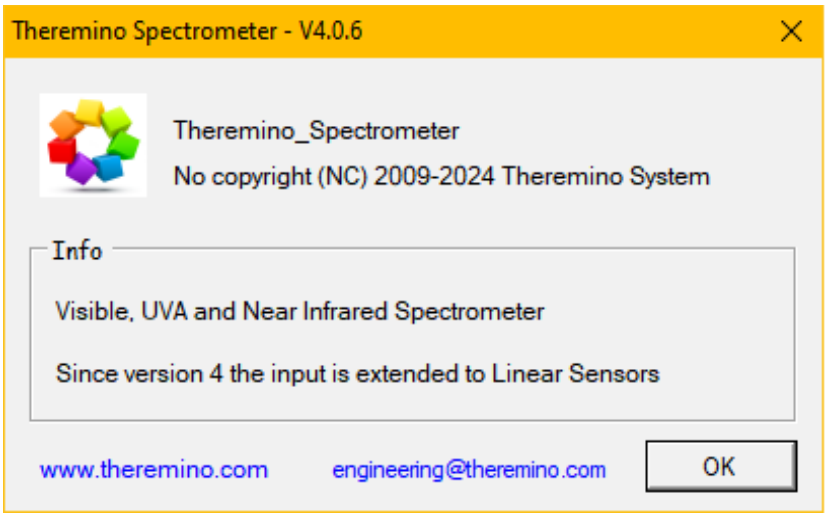
Language choice



Application instruction file.

Construction instructions and example spectra.

The last line opens the software working folder, to check and edit language files and other files.



The last menu item opens this page which contains information about the application.

In the last line below you will find the link to the site and the email address to write to us.

Top bar controls

Save Spectrum

This button saves the image of only the spectrum area.

Save total

This button saves the overall image of the application.

Save data file

This button writes the spectrum data to a file. The data file does not contain changes made in the "Scale logarithmicity" box and other controls found in the lower status bar.

Time Box

This is the waiting time. It starts when you press the button and after this time the data file is written.

Repeat

This button enables repeat. If it is enabled, the time count starts again as soon as the file is written.

If you enable "repeat" the saving of files will also be repeated at the end of the "Average" period.

Options

This button hides rarely used controls and enlarges the spectrum area, as shown on the next page.

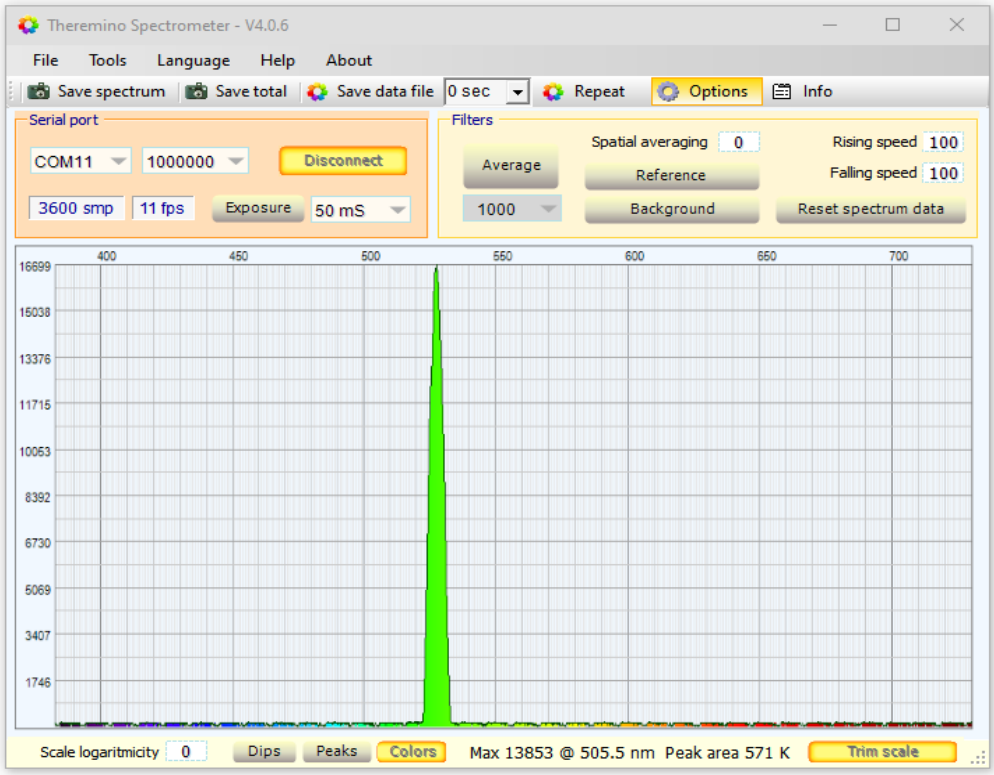
Information

This button opens and closes the information window that you see on the next page.

Options and Information

Options

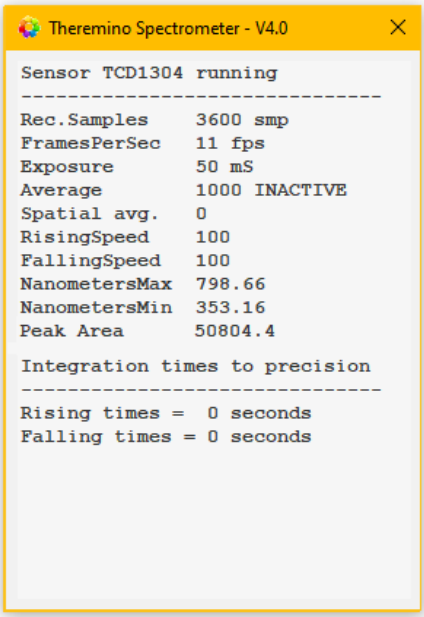
The "Options" button hides rarely used controls and enlarges the spectrum area, as shown in this image.

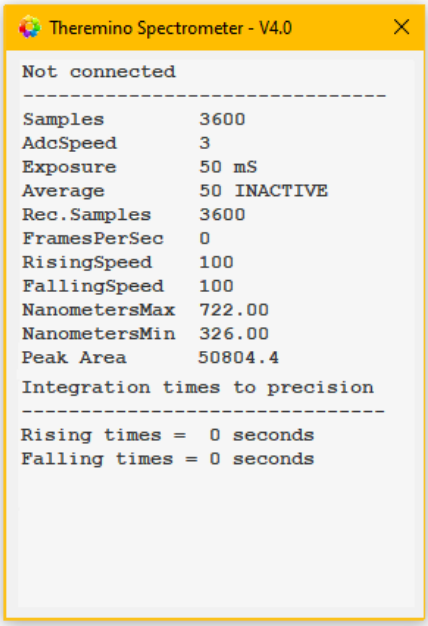


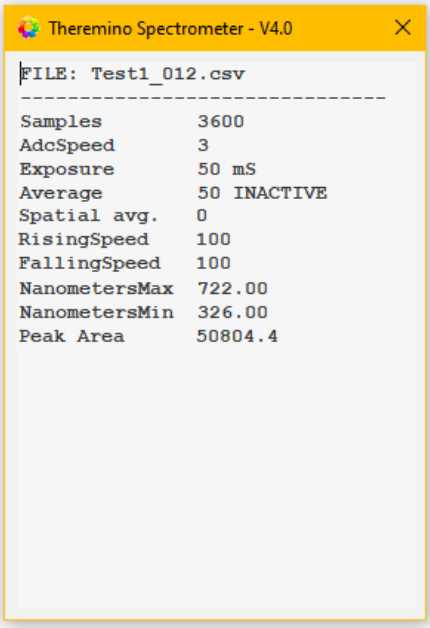
Information

The "Information" button opens and closes the information window that you see in the following images.

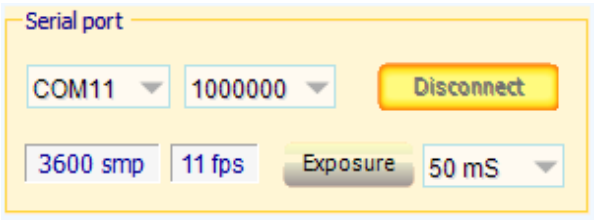
The information changes depending on whether the program is running or stopped, or whether it is viewing a saved file.







Serial port panel



This panel is only visible when you set the linear sensors, TCD1304 or TCD1254 in the Tools menu.

If you use a WebCam it is replaced with the Video Inputs panel.

The serial port must be set to be able to communicate with the module that reads the sensor.

To understand which is the correct COM port:

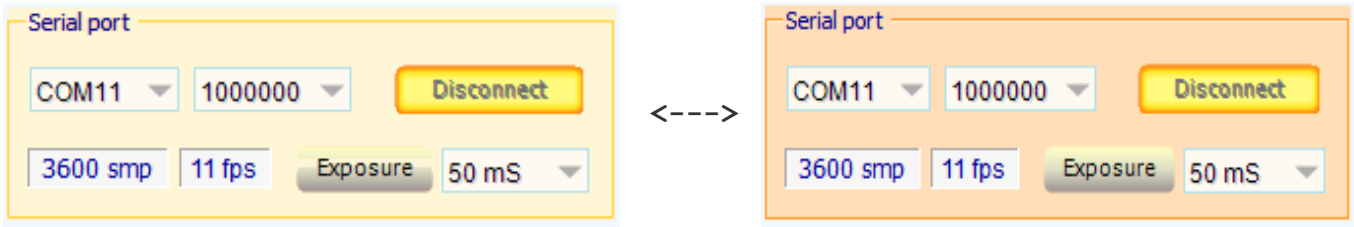
- Disconnect the module from the USB
- The COM box opens and records which ports are present
- Reconnect the module to the USB
- The COM box opens again
- The new door that appears is the one to choose

Communication defects

- If a port does not appear, check the USB cable.
- If it is not the cable then the module may not have been programmed.
- Or the CH340 driver is not installed

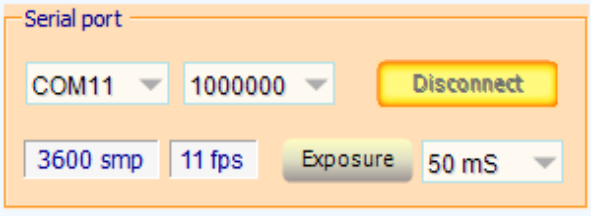
The communication speed "Baud rate" should always be set to one megabit per second (1000000). You should only change it if you are using a firmware other than the one we wrote for the Nano module.

When you enable the connection with the Connect / Disconnect button the bottom of this panel should flash, if it is not flashing then there is no data coming from the sensor.



The flashing speed indicates the frequency of data arrival, each time data arrives the background of the panel changes color.

Serial Port Panel - Part 2



This panel is only visible when you set the linear sensors, TCD1304 or TCD1254 in the Tools menu.

If you use a WebCam it is replaced with the Video Inputs panel.

Boxes to the left of the "Exposure" button

The first of these two boxes indicates how many samples are actually received by the sensor (in this example it is 3600 samples).

The second box indicates how many whole spectra are received per second (in this case it is 9 spectra per second).

Exposure

This time is adjustable from 10 micro-seconds up to very long times.

The sensor accumulates photons over the exposure time and can become extremely sensitive.

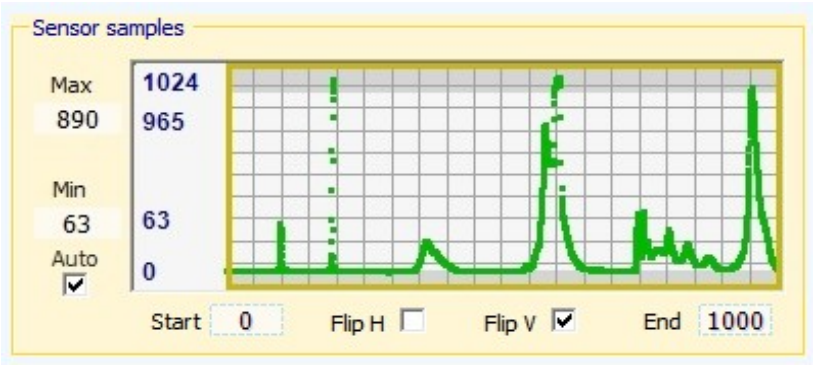
Increasing the exposure beyond 100 milliseconds the acquisition rate decreases significantly.

Self-exposure

Clicking the "Exposure" box enables autoexposure, which automatically adjusts the exposure based on the available light.

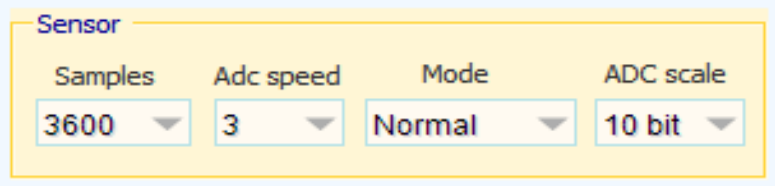
Automatic exposure is limited to a maximum of two seconds. Longer times are set manually and in these cases the acquisition frequency decreases significantly.

For auto exposure to work properly, you need to manually adjust the "Max" box in the "Samples from Sensor" panel, as explained below.



- You start by increasing the exposure and giving enough light until the sensor is saturated and you see the tips become flat.
- Then set the "Max" value very high and enable auto exposure.
- Finally, gradually decrease the "Max" value until the exposure automatically drops and the peaks are no longer saturated.

Sensor adjustment panel



This panel is only visible when you set the linear sensors, TCD1304 or TCD1254 in the Tools menu.

If you use a WebCam it is replaced with the Video Inputs panel.

Champions

Adjust the number of samples (sensor pixels) to read.

TCD1304DG Sensor

The TCD1304DG sensor works well up to 3600 samples.
Setting 2000 may, in some cases, make the measurements slightly more stable.
We recommend always setting it to 3600.

TCD1304AP Sensor

The TCD1304AP sensor only works up to 1200 samples.
Setting it to 1000 or better to 800has a slightly greater dynamic range.
We recommend setting this to 1000.

TCD1254 Sensor

The TCD1254 sensor is expected to operate at 2500 samples.
By setting values other than 2500 the measurements may, in some cases, be slightly more stable.

IMPORTANT
Calibrations are only valid for the sensor and the number of samples on which they were made.
Changing the number of samples will make the calibrations inaccurate.
By changing the sensor they will become totally wrong.

ADC Speed

The ADC speed is normally set to 3
We used the lower speeds for testing but we do not recommend using them.
The firmware file lists the ADC clock frequencies by setting 3, 2 and 1

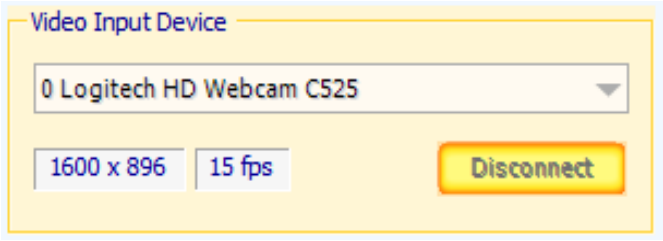
Way

Leave set to "Normal". The other options are only for checking the module and USB, without having to connect the sensor.

Adc Scale

Normally (Nano module) the ADC scale is 10 bits. You should only change this value if you are using a module other than Nano and writing a firmware for it.

Video input device panel



This panel is only visible when using a WebCam.

If you set linear sensors, TCD1304 or TCD1254 in the Tools menu, then this panel is replaced with the panel for the serial port.

Top box with the name of the WebCam

Clicking on it displays the list of video devices currently connected to the PC.

Boxes to the left of the "Disconnect" button

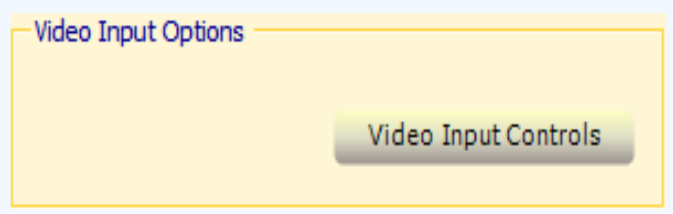
The first of these two boxes indicates how many pixels are actually received by the WebCam (in this example they are 1600 horizontal and 896 vertical)

The second box indicates how many images (frames) are received per second (in this case it is 15 images per second).

Connect / Disconnect button

It is used to start or stop receiving data from the WebCam.

Video input options panel



This panel is only visible when using a WebCam.

If you set linear sensors, TCD1304 or TCD1254 in the Tools menu, then this panel is replaced with the panel for the serial port.

Video Input Controls

This button opens and closes the WebCam settings panel which is explained on the next page.

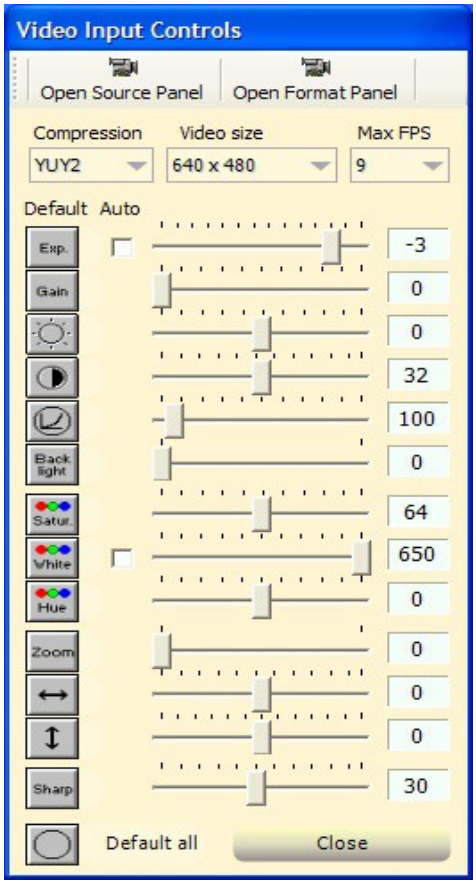
The empty places in this panel are left free on purpose.
to be able to add exposure time to WebCams as well.

If we can find WebCam with adjustable exposure time
We will add it in the next releases.

WebCam Adjustment Panel

These properties are accessible only if you use video devices with “WDM” type drivers.If you only have “VFW” (Video For Windows) drivers you will necessarily need “Open source panel” and “Open format panel” as illustrated on the next page.

Depending on the video device selected, some of these properties may be missing or disabled.



Exposure time
I earn
Brightness
Contrast
Range
Backlight
Saturation
White balance
Dye
Zoom
Pan
Tilt
Sharpness
Default for all parameters

Many video device drivers contain errors or are written "roughly". One of the most common defects is losing settings (you reopen the program and something in this panel has changed). Some drivers re-enable the "Auto" boxes every time you turn on the computer or change USB ports. In other cases it also happens that at startup, the actual settings of "White Balance" or "Compression" are not those shown in this panel.

These defects are not due to the Theremino Spectrometer application, if you replace the driver everything goes back to normal (or the defects change).

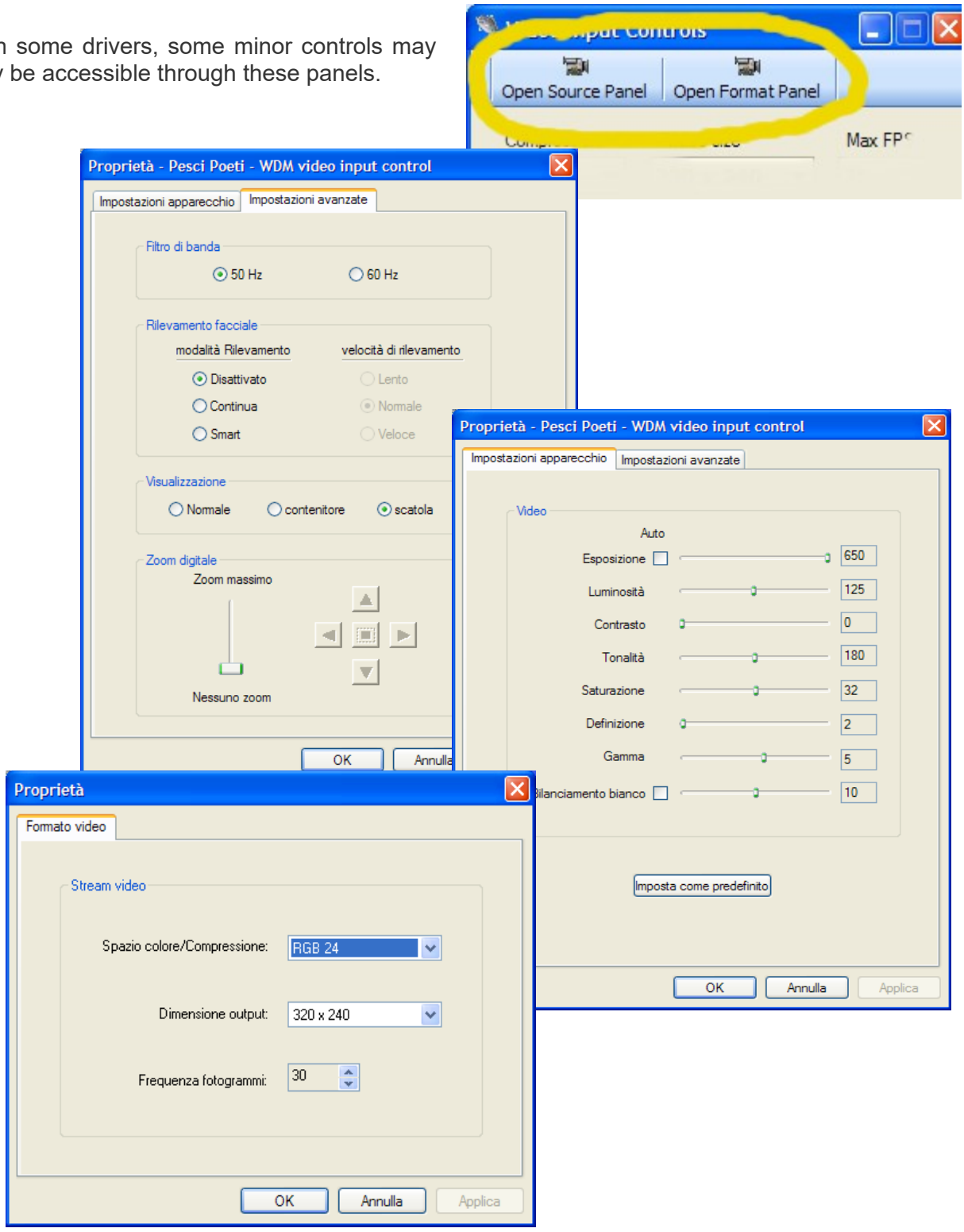
If you can't find a better driver, you'll have to get used to its flaws. Check these settings every time you start a measurement session and possibly change some controls until your video device behaves correctly.

This panel can be docked to the right or left of the main window, or positioned wherever you like on the screen. Moving it with the mouse will remember its position.

VFW WebCam Settings

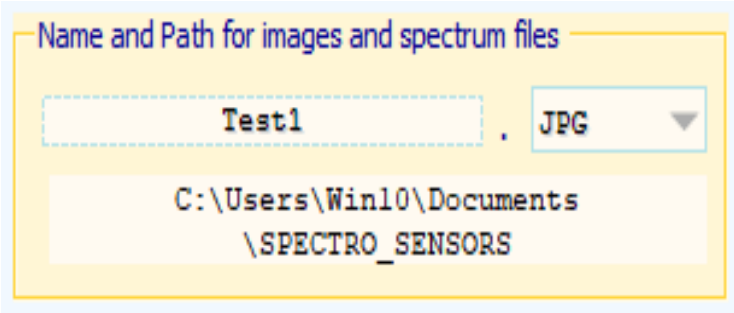
If the video device driver (WebCam) is of the VFW type, its properties are accessible only through the "Adjustments Panel" and the "Format Panel".

With some drivers, some minor controls may only be accessible through these panels.



Panel for image and data files

Name



Here you set a name for the images and files to be saved, with each shot the final numbers will be automatically incremented.

The number of digits is respected, therefore if you want a four-digit numbering you must start, for example, with "xxxx 0001" which will be incremented to "xxxx 0002",“xxxx 0003” etc...

It doesn't matter what's to the left of the digits, space or hyphen or whatever, the first non-numeric character from the right is considered the end of the name.

The name cannot start or end with a space, any leading or trailing spaces are automatically removed.

Path

This is the destination folder for the image and spectrum data files, to change it double click the box, choose a folder and press OK.

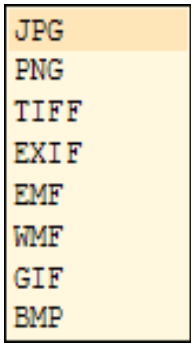
You can also change the path manually or by copying and pasting.

You can easily open the file folder by right-clicking on this box.

Once the folder is open, you can also read the spectral data files by dragging them with the mouse from the folder above to the application.

File format

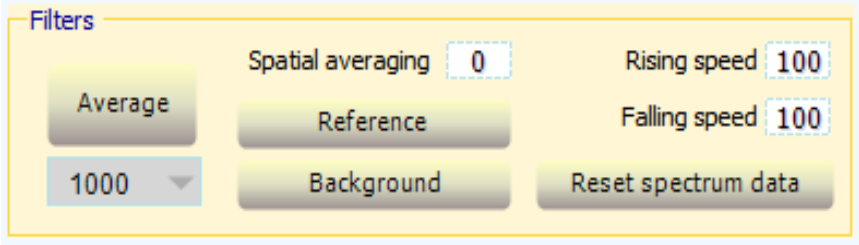
Normally the JPG format is used with quality 100. If you want a higher quality a good format is PNG which uses lossless compression.



If a JPG image is loaded and then saved a very large number of times, theoretically it should gradually deteriorate (but in practice no changes are noticeable). PNG images, on the other hand, can be saved and reloaded an infinite number of times and always remain identical to the original.

TIFF, EXIF and BMP are also lossless formats but produce unnecessarily large files.

Filter panel



Average

Normally you keep this value at 1, but you can raise it up to 1000 to average the data and eliminate noise.

The average does not take effect until you enable it by pressing the average button.
In some cases it may take many hours to complete the average
See detailed explanations on the next page.

Space media

This filter performs a "smoothing" interpolation between adjacent values. If used sparingly, it can significantly reduce noise without altering the data you intend to measure.

Normally set from 0 to 3. Raising this value to 5 or in extreme cases, up to 10, eliminates noise and steps from the graph. As a trade-off, you must accept a broadening of the lines and a reduction in resolution.

Reference

By pressing this button, all the values of the spectrum are "equalized" to the maximum measured value. In this way, subsequent variations, both positive (increase in light) and negative (decrease in light), can be detected.

One of the main uses of this reference is to make absorption measurements, for example to measure the response curve of colored filters or the absorption of various substances.

See notes on absorption measurements in "Appendix 3"

Subtraction of the fund

Background subtraction is used to eliminate noise and disturbances found in the lower part of the spectrum.

In essence, it allows you to eliminate from the measured signal all those components that are not directly attributable to the sample being analyzed, but which can influence the measurement.

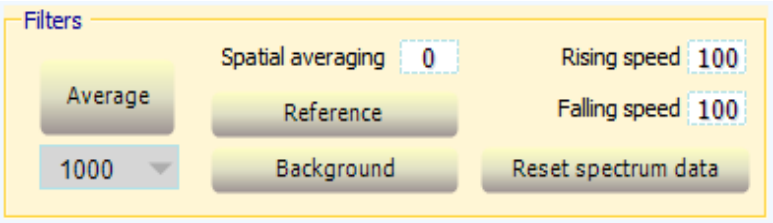
Subtracting the background significantly improves the signal-to-noise ratio, making it easier to identify characteristic peaks in the sample.

Both "Reference" and "Background Subtraction" should be used immediately.
If time passes, and you use them later, maybe after days using a file,
the quality of the subtraction degrades significantly due to the changes
that have occurred in the sensor, the sample and the software adjustments.

Filter Panel - Average Effects

This technique significantly increases the stability and quality of the data, as explained by Ocean Optics in figure 7 of ***this page***, but it must be remembered that In some cases it may take many hours to complete the average.

If you set it to for example 1000 and you receive 10 samples per second (as explained in the next chapter) then it will take 100 seconds to average all 1000 received spectra.



Normally you keep this value at 1, but you can raise it up to 1000 to average the data and eliminate noise.

- To activate the average you must enable it with the "Average" button
- During the entire averaging time, each new spectrum received by the sensor is displayed with the average that has been made up to that moment and a progressive number appears in place of the word "Average".
- Upon completion of the set average, the data file is automatically saved.
- After saving the file the application disconnects from the sensor, unless the "Redo" button in the top toolbar is enabled.
- If the "Repeat" button is enabled then after saving the file the averaging starts from scratch and the process will continue to repeat until you disable the averaging or the "Repeat" button.

Number of samples per second

Using a Nano module and a TCD1304DG or a TCD1254 it is good to set Adc speed = 3 and with this setting the ADC sampling time is 26 uS

So with 3600 samples the sampling time is 93.6 mS which leads to a maximum of 11 spectra per second.

With the 2500 samples of the TCD1254, however, you can get approximately 16 spectra per second.

With 500 samples you should get 76 spectra per second but in reality the maximum is 64 because there are other small delays due to the USB communication.

The next table shows the times required to read samples from the sensor.

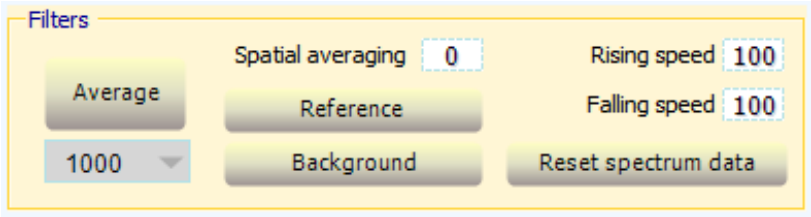
Samples	3600	3000	2500	2000	1500	1200	1000	800	600	500
Sampling time mS	93.6	78	65	52	39	31.2	26	20.8	15.6	13
Frames per second	11	13	16	20	26	32	40	50	64	64

These are the maximum speeds that can be achieved
and you can only get them by setting very short exposure times.
(10 milliseconds or less).

Filter Panel - Climb and Descent Speed

These two speeds have a great effect on the data and can effectively reduce noise.

Be careful to keep them at 100 if you don't use them because with very low numbers Integration times can become extremely long, as explained on the next page.



Climbing speed

Raising this rate to 100 updates the spectrum data to the peak value of the light received for each frequency. Lower numbers average the current value with the new data coming from the camera.

Descent speed

This is the rate at which the stored data fades over time. You can lower this rate to zero, in which case the data stored in the spectrum does not fade, but remains unchanged until you press "Spectrum Reset".

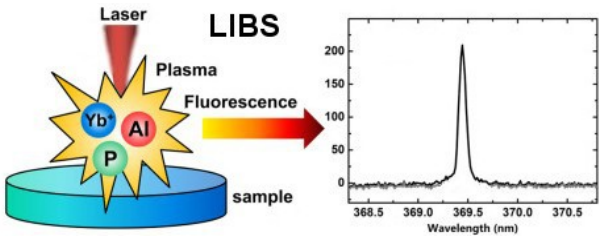
Clear Spectrum Data

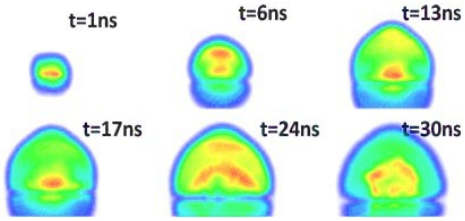
This button manually resets the spectrum. It is not necessary to use it, but some people may like to see the spectrum completely white before starting a new measurement.

How the ascent and descent speeds work

Typically, both of these speeds are kept at 100. Lowering them to 30 results in time integration, which reduces noise while still maintaining a fairly fast response to light variations.

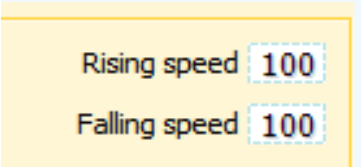
These two values can be lowered to obtain long or even infinite integration times (with zero descent rate). It is then possible to accumulate the data arriving from multiple single events, which could be for example the brief emissions of light caused by the laser-excited plasma in a LIBS spectrometer.





Long integration times could reduce noise and improve both small-signal sensitivity and spectral resolution.

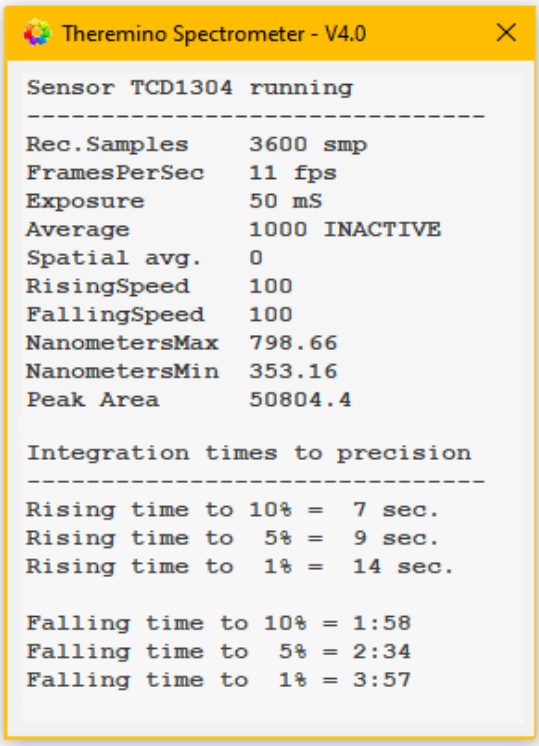
Integration times



These adjustments use an IIR filter to gradually approximate the final value, with a trend that stabilizes asymptotically.

IIR filters provide a rapid response to significant changes, but gradually adapt as the signal stabilizes. This makes them ideal for reducing noise without compromising response speed under dynamic conditions.

Unlike FIR filters, which have a fixed response time, IIR filters offer an adaptive response, adjusting the approximation rate based on the signal.

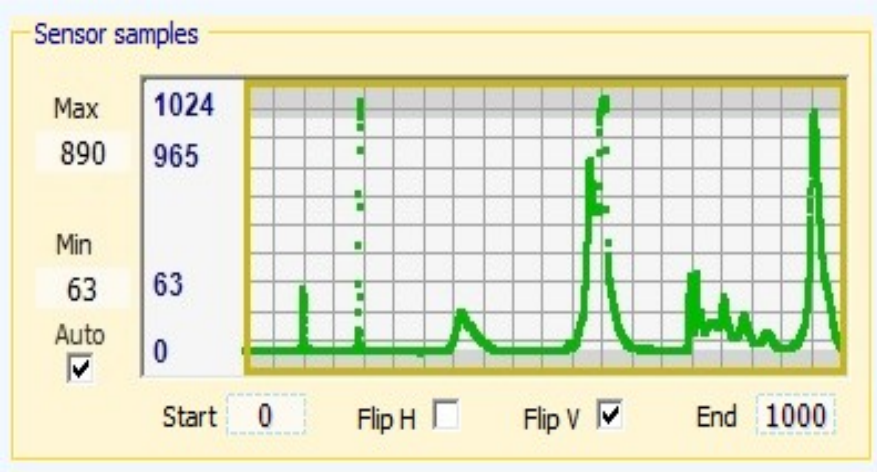


We have therefore added to the information window the calculation of the rising and falling times (Rising time and Falling time) necessary to reach the final value within a tolerance of 10%, 5% and 1%.

The calculation of rise and fall times varies depending on the type of sensor used: WebCam or linear sensor.

- For webcams, the calculation is based on the frame rate (fps), thus requiring that the WebCam be active, or have been active at least once since the application was started.
- For linear sensors, the calculation is based on a formula that takes into account the exposure time and other sensor settings, allowing an estimate even when the sensor is inactive.

Panel of samples arriving from the sensor



This panel is only visible when you set the linear sensors, TCD1304 or TCD1254 in the Tools menu.

If you use a WebCam it is replaced with the panel that shows the image of the WebCam, which is explained in the next pages.

Max, Min,Car

These three commands adapt the software to the sensor and are explained on the next page.

Start

This box sets the start of the scale, resulting in the magnification of a limited area of the spectrum.

Inv. H

Horizontal reversal of the signal arriving from the sensor.

Inv. V

Vertical reversal of the signal coming from the sensor.
For TCD1304 and TCD1254 sensors, with our firmware and the "Nano" module, this box must be enabled.

End

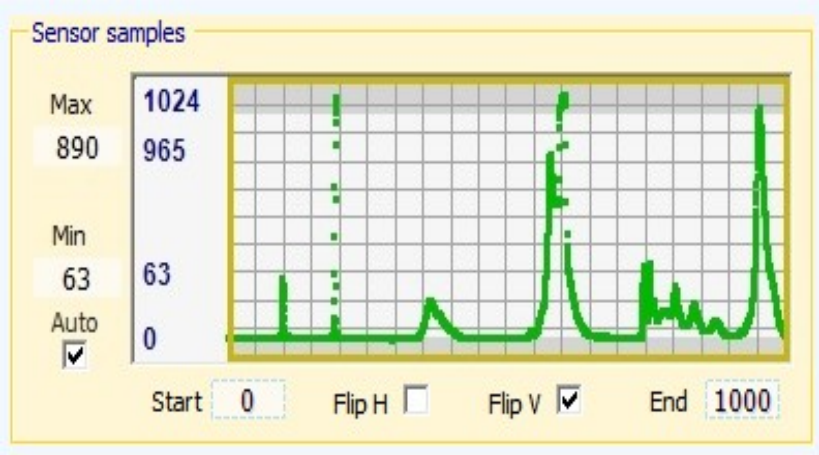
This box sets the end of the scale, resulting in the magnification of a limited area of the spectrum.

You can adjust the parameters**Start**And**End**
even by zooming and moving the spectrum graph with the mouse wheel
as explained in the next pages.

Max and Min adjustments

These adjustments adapt the software to the sensor since the sensors are different from each other and have very large tolerances.

Normally the values produced by the sensors cover about a third of the scale (the bright area in this image) but in some cases this area could be expanded with an operational amplifier and two trimmers.



This panel is only visible when you set the linear sensors, TCD1304 or TCD1254 in the Tools menu.

If you use a WebCam it is replaced with the panel that shows the imageof the WebCam, which is explained on the next page.

Max

This value is essential for the proper functioning of the "Auto exposure"

It should be adjusted so that the upper grey band is a little lower than the maximum signal that is obtained when the tips saturate and flatten out at the top.

If you set Max too high, "Auto Exposure" may in some cases produce saturated peaks (with a flattened tip).

If you set Max too low, "Auto Exposure" may in some cases produce peaks that are too low and therefore not make good use of the available vertical space.

The value immediately to the right of the Max box (685 in this image) indicates how much the tip of the highest peak is. You can use this value as a guideline for adjusting max.

Min

It is used to set the start of the useful scale at the bottom.

The correct setting is achieved when the lower grey band just touches the lowest parts of the signal.

Normally you set it automatically, by checking the "Auto" box. But in some cases you may want to set it in a stable way and independent of the small variations, which it could have if the lighting conditions change.

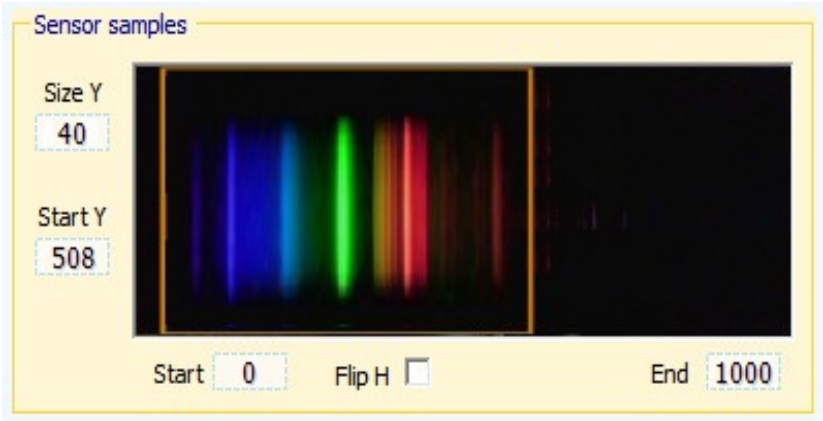
Car

Normally you enable this box and the Min value is set automatically.

Incoming WebCam Samples Panel

This panel is only visible when using a WebCam.

If you set the linear sensors, TCD1304 or TCD1254 in the Tools menu, then this panel is replaced with the sensor panel explained on the previous pages.



Size Y

This value determines the number of pixel rows used for analysis. The software averages the values of all the rows, which improves sensitivity and reduces noise. Another advantage of using an area composed of many rows is that even small errors in vertical position due to imperfect alignment of the spectrometer are tolerable.

Leave some margin above and below the spectrum. In some special cases (badly aligned diffraction grating) you can get a slight increase in resolution by enlarging the spectrum vertically until you can see only the central part.

This is more or less the recommended zoom level.

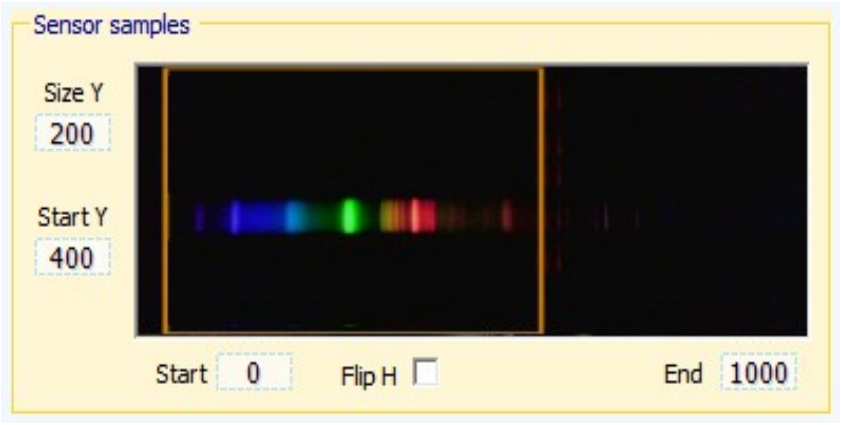
You could also zoom in a little more but don't overdo it because it's best to average across many vertical pixels.

Start Y

Adjust so that the spectrum is centered vertically.

Here the spectrum is too low so the vertical position must be corrected with StartY.

Adjusting the Start and End



This panel is only visible when using a WebCam.

If you set the linear sensors, TCD1304 or TCD1254 in the Tools menu, then this panel is replaced with the sensor panel explained on the previous pages.

Start

This box sets the start of the scale, resulting in the magnification of a limited area of the spectrum.

Inv.H

Horizontal image flip. Using this command causes a small additional load on the CPU. Therefore, you should only use it if you have fixed the webcam on the wrong wall of the spectrometer or upside down. If possible, modify the spectrometer so that it does not have to be used.

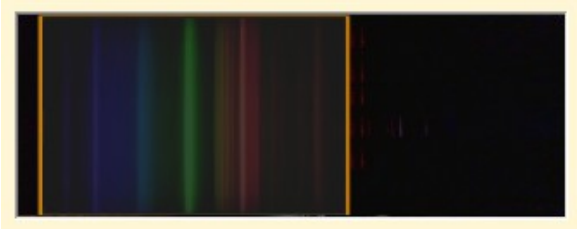
End

This box sets the end of the scale, resulting in the magnification of a limited area of the spectrum.

For quick and easy adjustment of the boxes
press the left mouse button on them
and, holding it down, move the mouse up and down.

The automatic gain

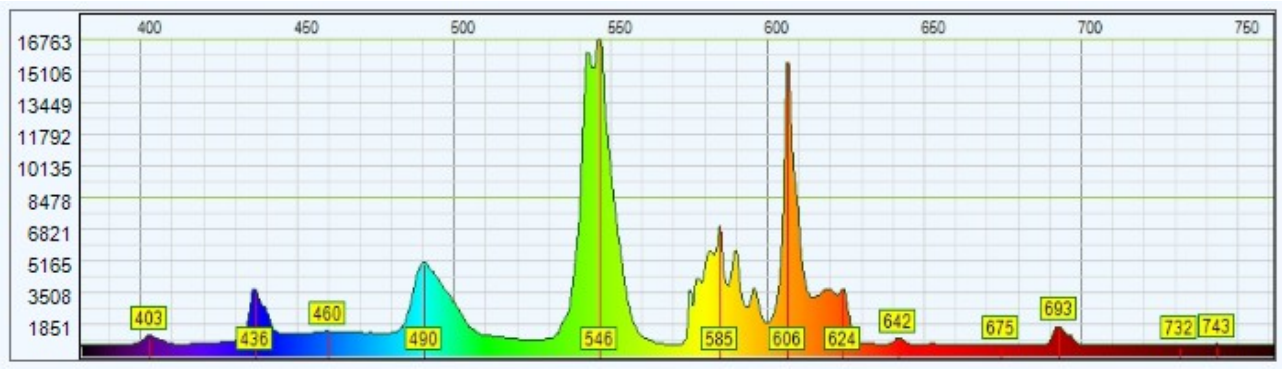
Since version 5.0 the WebCam signal display window automatically adjusts to low brightness.



Poor signal with version 4

The same signal corrected by version 5

The spectrum display area

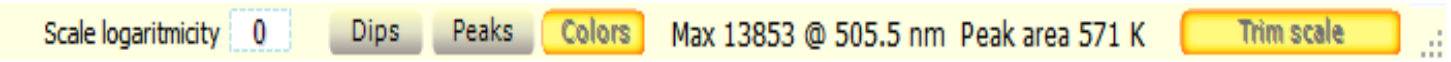


To enlarge the spectrumyou click on it with the left mouse button and then use the wheel.

To move ityou click the left mouse button and then move the mouse left and right, holding the button down.

The spectrum can be displayed in several ways,The related commands are explained in the next pages.

The lower command bar



Measurement indicator

The first box on the left of this bar has two functions:

Value 8223 @ 505.5 nm Peak area 571 K

When the mouse cursor is in the plot area, the box shows the (relative) intensity values, nanometers, and the area calculation of all visible peaks.

Max value 16763 @ 505.5 nm Peak area 571 K

When the cursor is outside the plot area, the box shows the value and nanometers of the highest peak, and the area calculation of all visible peaks.

The Peak area value is the measure of the integral of all peaks in the visible area.
To use it, you must manually crop the peak of interest.

Logarithmicity

If set to zero the vertical scale is linear.
By increasing the value (up to 10) the scale becomes logarithmic and the low values are emphasized.
By increasing the value (up to -10) the scale becomes exponential and the spectrum lines narrow.

Valleys

Enabling measurement labels for chart lows.

Peaks

Enabling measurement labels for chart maximums.

Colors

Enabling wavelength-related coloring.

The corrections that are made with the "Logarithmicity", "Valleys", "Peaks" and "Colors" commands
They only act on the spectrum display window
and do not change the values of data files that are saved to disk.

Scale Calibration

Enable labels for horizontal scale calibration (nanometers).
For calibration details see the next pages.

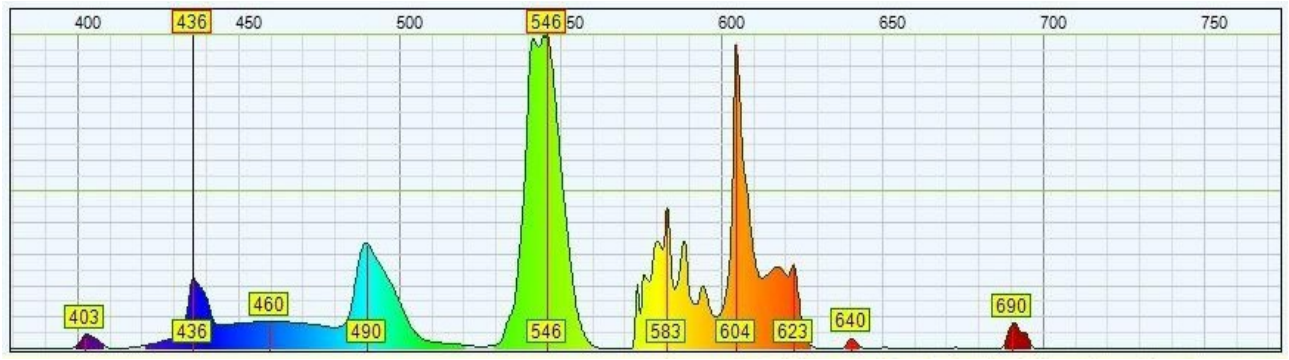
Appendix 1 - Calibration of the scale

To calibrate the spectrometer scale, a fluorescent lamp is needed.

You can use one of the energy-saving lamps that are used for home lighting, or you can prepare a convenient calibration source, following the instructions on the last pages of the file "Theremino Spectrometer Construction".

Perform calibration

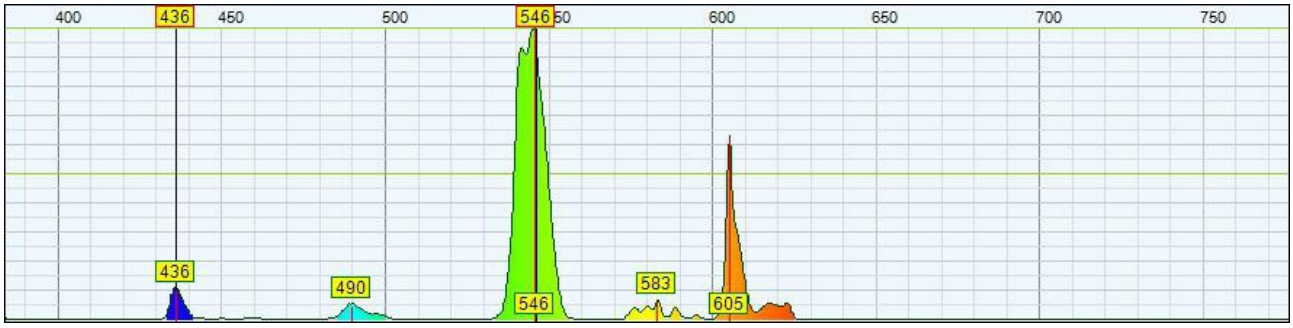
- Place the lamp near the spectrometer's entrance slit and adjust the "Exposure" to get a graph similar to the following.
- Make sure the "Reference" and "Valleys" buttons are not pressed and the "Peaks" and "Colors" buttons are pressed.
- Press the "Scale Calibration" button and locate the two new labels that appear at the top, in the scale numbers area.
- Drag the labels one at a time,holding down the left mouse button,until they are at the tip of the two characteristic peaks of mercury at 436 and 546 nm.



Here you can see the two peaks of mercury and the labels at 436 and 546 appearing.

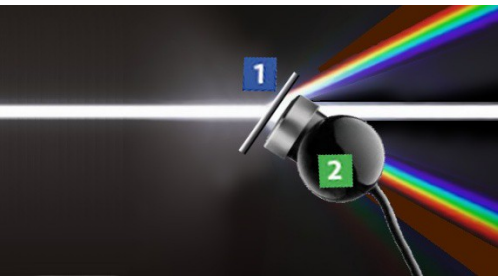
The calibration points may not even be 436 and 546. To set them, see the menu commands on page 4.

To calibrate more precisely, zoom in on the area of interest with the wheel and the left mouse button. Also move the lamp away so that the peaks do not have flattened tips and their maximum is more evident.



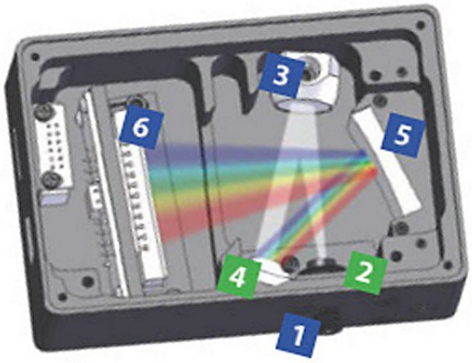
By moving the lamp away the peaks become narrower and their maxima become more precise.

Appendix 2 - Multipoint Calibrations



In previous versions of the application the calibration points were always two, usually 436 and 546 nanometers, and with two points you get a calibration that is a single straight line, whose slope and position can be defined with two points.

Two-point calibration is appropriate when using a transmission diffraction grating (1) and a simple optical path ending on a WebCam (2), or on a linear sensor.



Some optical benches, however, use a collimating mirror (3), a reflection grating (4), a focusing mirror (5) and a linear sensor (6).

These benches have the advantage of better concentrating the available light on the sensor, but on the other hand they are very difficult to adjust and have significant linearity defects.

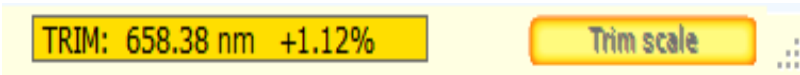
When using these benches, a simple straight line is no longer sufficient, but it must be broken into several parts and defined with more than two calibration points.

For which from version 4 onwards we have added the possibility to perform calibrations multi-point, for greater accuracy in the presence of non-linearities.

There is no limit to the number of points that can be added, but we do not recommend exaggerating, both because for each point you should have a safe reference, but also because if the points are too close to each other, the slightest variation of one of the two would cause exaggerated variations in slope. These unnatural variations in slope would not correspond to physical reality and would create more errors than those that you would like to correct.

- To add calibration points, go to the area above the spectrum, away from the already yellow labels.existing and press the right mouse button.
- To delete a calibration point, go to the area above the spectrum, above is a yellow label of an existing point and press the right mouse button.
- To move a calibration point, go to its label, press and hold the left mouse button, and move the label to the right or left.
- To change the value in nanometers of a calibration point, press the CTRL key on the keyboard and use the left mouse button as if to move it.

As you adjust the calibration points, an orange label appears in the center of the bottom bar.



This label indicates the exact value in nanometers of the selected point and the percentage of nonlinearity that the point produces on the calibration curve.

Forperform a more accurate calibration
It is a good idea to zoom in on the relevant spectrum area using the mouse wheel.

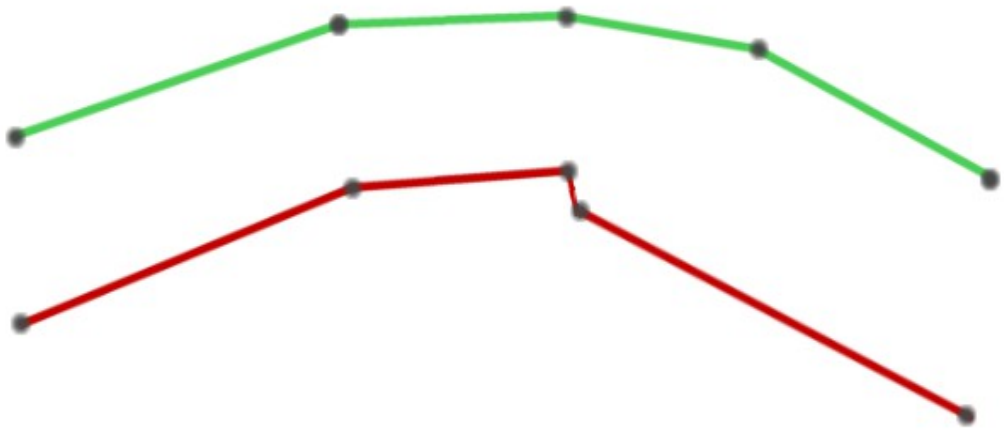
Appendix 2 - Incorrect Calibrations

If you are a mere mortal, you will not have a set of calibration sources, such as hollow cathode lamps and other similar expensive and fragile gadgets.

So the only two truly safe calibration points you have are 436 and 546. All the others have errors of up to several nanometers and should not be used.

So avoid adding unsafe calibration points and, even worse, placing them close to each other, for the following reasons:

- **Source redundancy:** Each point requires a precise source. Excess points introduce greater errors than a few safe points.
- **Unnatural jumps:** Points that are too close together cause sudden and unreliable changes in the calibration curve.
- **Curve instability:** Small variations in adjacent points cause exaggerated and unnatural slopes (see red line). Such variations are physically impossible and introduce more errors than one would like to correct.



Calibration points too close to each other cause unnatural slope variations as shown in the red line.

These variations in slope are evidently impossible in reality. and create more errors than they would like to correct.

Calibration is a delicate balance between accuracy and simplicity. Too many points can lead to apparent accuracy, but at the expense of simplicity and accuracy of the model. **A curve that is too complex does not adequately describe the behavior of the system**.

For a more complete explanation read the pages ***"Overfitting" by Wikipedia***.

Appendix 3 - Absorption measures

Absorption measurements are performed with the "Reference" button and are used to measure the response curve of colored filters and the absorption of various substances, such as olive oil.

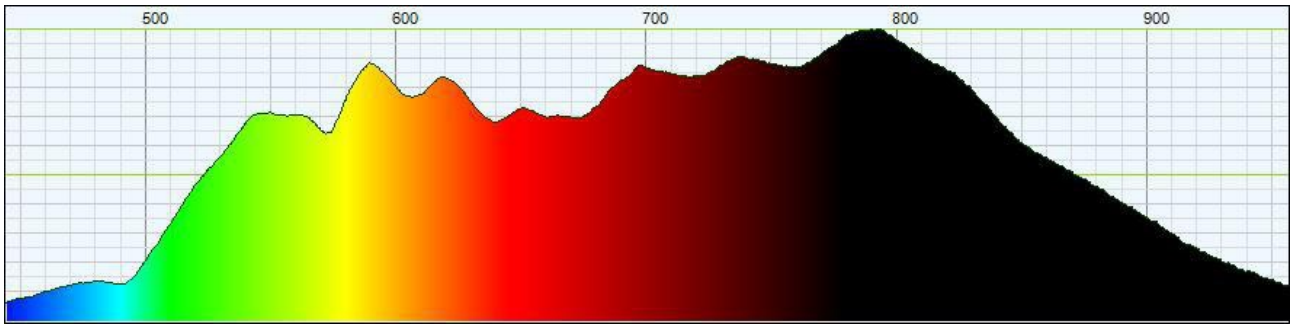
For these measurements, it is necessary to have a source that emits light in the entire spectrum (or at least in the area to be measured). Sources of this type are called "Broadband". Instructions for preparing Broadband sources are in the last pages of the file "Theremino Spectrometer Construction".

Perform an absorption measurement

- Make sure the "Valleys" and "Peaks" buttons are not pressed and that "Colors" is.
- Open the aperture fully to get as much light as possible (filter measurements don't require much resolution).
- Adjust the "Filter" and "Speed" controls to 30 (with very high or low values it becomes difficult to take absorption measurements).
- Place the "broadband" lamp close to the spectrometer's entrance slit but leaving enough space between the lamp and the spectrometer for the filter or test tube to be measured.
- Adjust the position of the lamp to get good lighting.
- Raise the exposure control to cover a wide area of the spectrum. But you must not overdo the light and exposure, otherwise glare will occur (visible in the black window of the camera) and the measurements will be distorted. If there is too much light and too much exposure the spectrum will never go to zero, not even in the areas where the filters absorb all the light.
- Test by pressing the "Reference" button if the covered area is sufficient.
- Frame the area of interest with "Start X" and "End X" or with the mouse.
- Before inserting the sample to be measured, press the "Reference" button
- From now on, keep both the lamp and the spectrometer still. If they touch when inserting the sample, then the reference must be repeated.
- Insert the sample, check the spectrum and possibly save its image without letting too much time pass (the reference deteriorates over time due to heating of the light source and other mechanical causes).
- If a lot of time has passed or the light source has moved, remove the sample and check that the reference is still valid (top of the spectrum aligned at the top).
- To restore the reference, first remove the sample and then disable and re-enable the "Reference" button.

On the following pages the measurement procedure is explained with images.

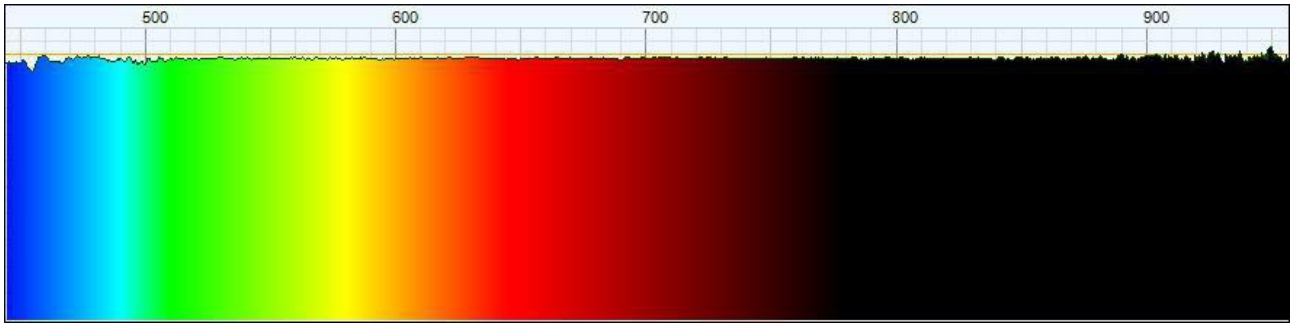
Appendix 3 - Absorption measures



This is the spectrum of a small incandescent lamp.

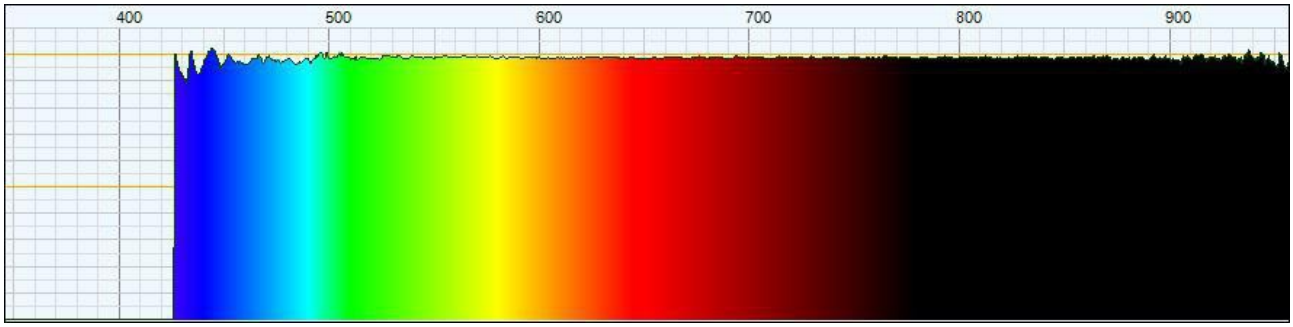
For this lamp the useful zone is from 450 to 950 nm so we have adjusted the scale to see only this zone. (The "useful zone" is considered to be the zone in which the lamp emits at least 15-20% of energy).

It would have been preferable to have a more uniform light source (a broadband or at least a halogen), but such sources are expensive, difficult to build and heat up a lot. So for these examples we will settle.



By pressing the "Reference" button you can verify that the selected area is actually entirely usable.

Note that in the terminal areas, where the energy is low, the line becomes rougher. In these areas measurements are still possible but will be less precise.



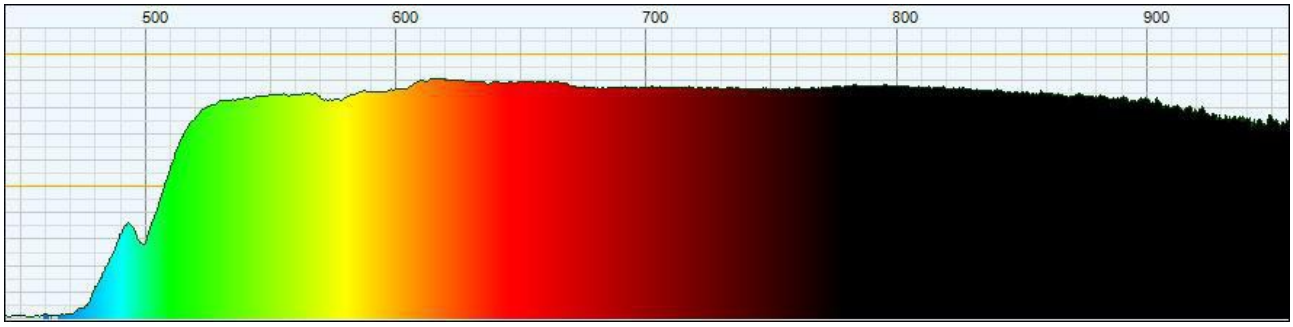
Here you see what happens if you press "Reference" using too large an area.

The area below 450 nm has too little light for measurements, and becomes progressively less smooth. Here you cannot see the movements but this area is not only imprecise but also very unstable.

Going further down, below 425 nm, the software decides that the area is too weak and unstable and discards it completely.

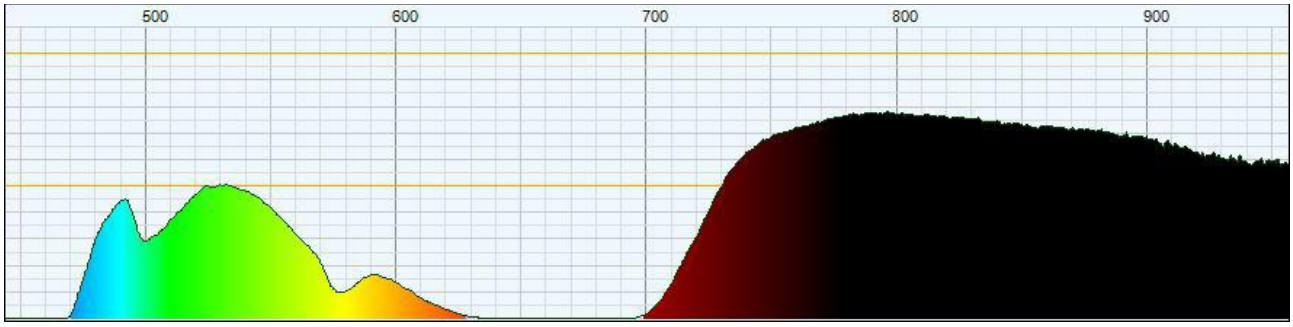
Appendix 3 - Absorption measures

In the following images you can see the spectrum of some colored filters.



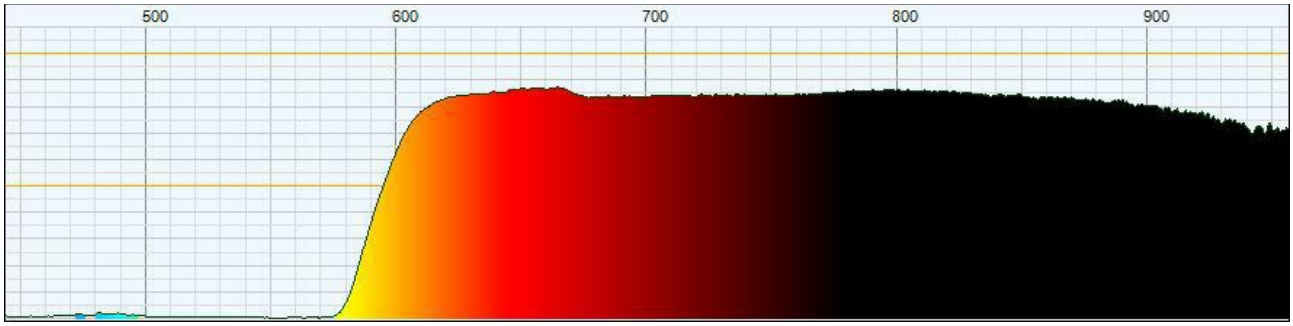
By interposing a yellow filter the spectrum is no longer at 100% (where the upper colored line is).

This yellow filter attenuates sharply from 500 nm down and lets through 80 to 90% of all other colors, up to the infrared.



This is the spectrum of a green filter.

This filter lets through 50% of the green energy and attenuates all other colors except infrared. Almost all filters let through infrared because otherwise the headlights would heat them up to ruin them.



This is the spectrum of a red filter.

This filter, in addition to its favorite color, also lets infrared pass through very well.

- - - - -

These spectra show the light that passes through, not the absorption. It would be more correct to call them "Transmission Spectra" but the term "absorption" is more commonly used.

To be clear, when the spectrum line is high it means that a lot of light has managed to pass, when it is low it means that the sample has "absorbed" a lot of light.

Appendix 3 - Absorption measures

Here is a simple setup for measuring colored filters, using a small bulb made from a flashlight.

To consume little and make the batteries last longer, we used a light bulb of just over 1 Watt (300mA at 6 Volts) which, powered at 4.5 Volts, consumes only 200mA.

With so little power you also need a good parabolic reflector.

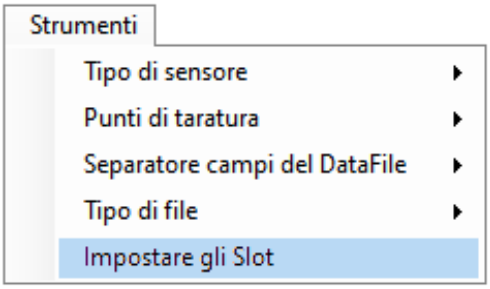
You can either take the bulb and the reflector from the flashlight, or you can use the entire flashlight.

Small tungsten bulbs like this one emit little blue light and almost no ultraviolet light.

It would be preferable to use a broadband xenon lamp, or a halogen one.

Read the lamp recommendations on the last pages of the "Spectrometer Construction" document.

Appendix 4 - Command Slots



The last item in the "Set Slots" tools menu allows you to change the two Command Slots.

Command slots (normally 31) Slot number of incoming commands from external applications.

Answer slots (normally 32) Slot number to which responses are sent.

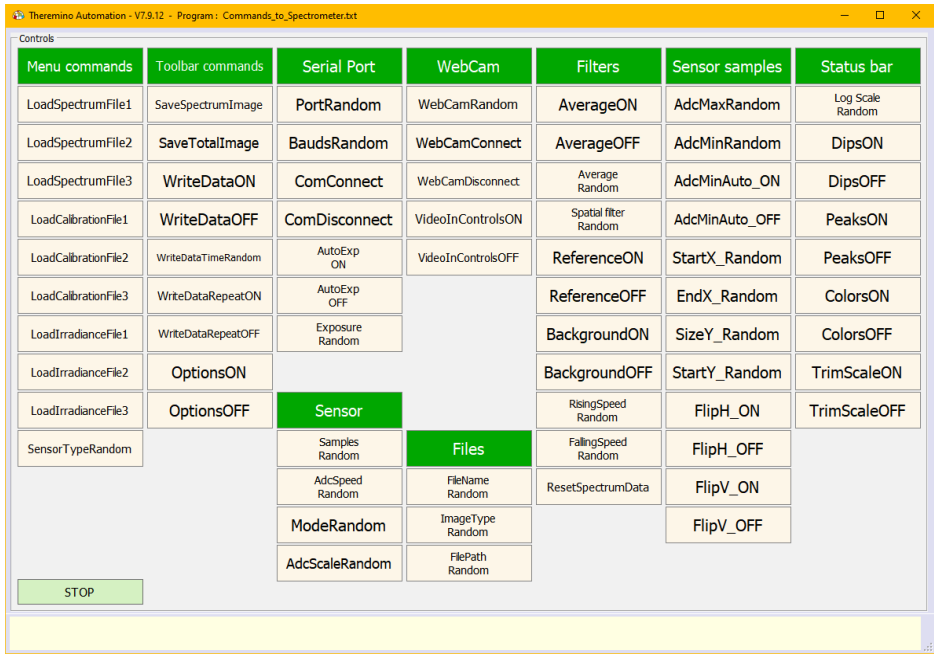
How Slots Work

Through the Slots other applications of the Theremino system can send commands (text strings) to guide the operation of the spectrometer.
If the command has been received by the Spectrometer application then the Command Slot is emptied and the possible responses are "OK" or "Command not recognized".

If the command has not been received it will remain in the Command Slot and there will be no response. In this case you will have to check that the Spectrometer application is active and that the command is sent in the command slot set in the application.

The list of commands is in the next pages. Experiment with the example that you see here on the right that is executed with the Automation application.

Each button sends a command and looking at how they are written you can easily do the same operations in your application.



You will find this example with the name "Commands_to_Spectrometer" in the examples folder "Automation_Examples \ Programs" that is next to the file "Theremino_Spectrometer.exe" with which you launch this spectrometer.

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The Programs folder also contains examples useful for creating coefficient files (see Appendix 7)

To use the examples, launch Automation.exe,
then select them with the LOAD button and execute them with RUN.

Appendix 5 - External Commands (Part 1)

The commands are exactly the same as those used with the mouse on the application window.

In the following list, commands with parameters separated by one or more spaces are just examples. To know all the values that can be used after the space, open the relevant boxes of the application and check in the drop-down list which values can be used.

In commands, uppercase or lowercase characters do not matter, nor does the number of spaces separating the command from the parameters.

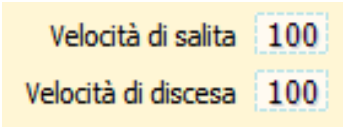
CONTROLS	PARAMETERS	
.....	.....	Menu
LoadSpectrumFile	Test_001.csv	
LoadCalibrationFile	Calib_WEBCAM.txt	
LoadIrradianceFile	Coeffs_FLAT.txt	
SensorType	TCD1304	
.....		Top command bar
SaveSpectrumImage		
SaveTotalImage		
WriteDataON		
WriteDataOFF		
WriteDataTime	3.0 sec	
WriteDataRepeatON		
WriteDataRepeatOFF		
OptionsON		
OptionsOFF		
.....		"Serial Port" Panel
ComPort	COM1	
Bauds	1000000	
ComConnect		
ComDisconnect		
AutoExpON		
AutoExpOFF		
Exposure	100 ms	
.....		"Sensor" panel
Samples	3600	
AdcSpeed	3	
Fashion	Normal	
AdcScale	10 bit	
.....		"Web Cam" panel
WebCam Index0		
WebCamConnect		
WebCamDisconnect		
VideoInControlsON		
VideoInControlsOFF		

Appendix 5 - External Commands (Part 2)

CONTROLS	PARAMETERS	
.....		"Files" panel
File Name	Test1	
ImageType	Jpg	
FilePath	C:\Users\Win10\Documents	
.....		"Filters" panel
AverageON		
AverageOFF		
Average	1	
SpatialFilter	0	
Reference_ON		
Reference_OFF		
Background_ON		
Background_OFF		
Rising Speed	100	
Falling Speed	100	
ResetSpectrumData		
.....		"Samples from sensor" panel
AdcMax	800	
AdcMin	320	
AdcMinAuto_ON		
AdcMinAuto_OFF		
StartX	0	
EndX	1000	
SizeY	20	
StartY	40	
FlipH_ON		
FlipH_OFF		
FlipV_ON		
FlipV_OFF		
.....		Lower status bar
LogScale	0	
Dips_ON		
Dips_OFF		
Peaks_ON		
Peaks_OFF		
Colors_ON		
Colors_OFF		
TrimScale_ON		
TrimScale_OFF		

Appendix 6 - Adjust the numerical boxes

The numeric boxes of Theremino Spectrometer (and of all the other applications of the Theremino system) were developed by us (note 1) to be more comfortable and flexible than the original Microsoft TextBoxes.



Numeric values are adjustable in multiple ways

- By clicking and holding the left mouse button and moving the mouse up and down.
- With the mouse wheel.
- Using the up and down arrow keys on your keyboard.
- With the normal methods used to write numbers on the keyboard.
- Using the normal selection and copy-paste methods.
- CTRL-CLICK sets the default value (only in some boxes that allow it)

- The method of moving the mouse up and down allows for large and quick adjustments.
- The mouse wheel allows for convenient and immediate adjustment.
- The arrow keys allow for fine adjustments without having to take your eyes off the operation in progress.

(Note 1)*Like all our software, the source files are available (Freeware and OpenSource under Creative Commons license) and can be downloaded from here:**www.theremino.com/downloads/uncategorized (section "Custom controls") These controls can be used at will in any project even without naming the source. The "Open" sources also serve as a guarantee that we have not included malware.*

Appendix 7 - Irradiance coefficients

Starting with version 5, it is possible to correct the received energy values using a file containing correction coefficients.

This allows you to compensate for differences in efficiency of optical components at different wavelengths.

- The coefficient file will contain a pair of values separated by spaces for each line.
- The first value represents the wavelength in nanometers (nm).
- The second value represents the corresponding correction coefficient.
- The wavelength values must be between ten and ten thousand nanometers.
- The correction coefficients must be greater than zero (usually 0.1 to 100).
- Either a dot or a comma can be used as a decimal separator.
- All lines that do not contain exactly two valid values are discarded.
- The file must contain the nanometers in ascending order and at least two valid lines.

The "Files / IrradianceCoeffs" folder contains some example files. You can see their effect by loading them via the "File" menu.

You can also create custom files to suit your needs, following the specifications above.

Interpolation and Extrapolation

Correction values for unspecified wavelengths (nanometers) are automatically calculated by interpolating between the two closest wavelengths. This process estimates the missing correction values based on the known data trends.

If the wavelength is greater than the last specified wavelength or less than the first, extrapolation is used. In this case, the data is extended beyond the known range, keeping the slope of the last two available values constant.

Irradiance Units

Using suitable light sources and calibrated equipment, you could also calibrate the vertical scale in different units of measurement, depending on your specific needs. For example: Watts per square meter (W/m²), Watts per square centimeter (W/cm²), Milliwatts per square centimeter (mW/cm²), Microwatts per square centimeter (µW/cm²) or even Photons per second per unit area, or Lux, MilliLux, MicroLux. Lumens etc..

It is important to choose the appropriate unit based on the expected brightness of the measurements. A unit of measurement that is too large could lead to small numerical values and loss of precision, while a unit that is too small could result in large and difficult to handle numbers.

The values measured on the vertical scale should fall within a range between one hundred and one hundred thousand,with correction coefficients approximately between 0.1 and 100.

In addition, to keep the calibration valid, it will also be necessary to keep the WebCam or linear sensor settings that are used identical.