



FiSpec FBG Sensor Systems

BraggSens handbook

Software versions covered in this handbook:

- FiSens BraggSens 1.89

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1 System installation

1.1 Software and driver installation

1.1.1 Driver installation

FiSpec devices communicate via a virtual COM port chip from FTDI. Connect the FiSpec device to the computer. If now automatic installation of the driver over windows update does not work or the computer does not have any internet access, the FTDI CDM driver delivered on the USB stick has to be installed:

```
[...] \FTDI driver\ CDM21228_Setup.exe
```

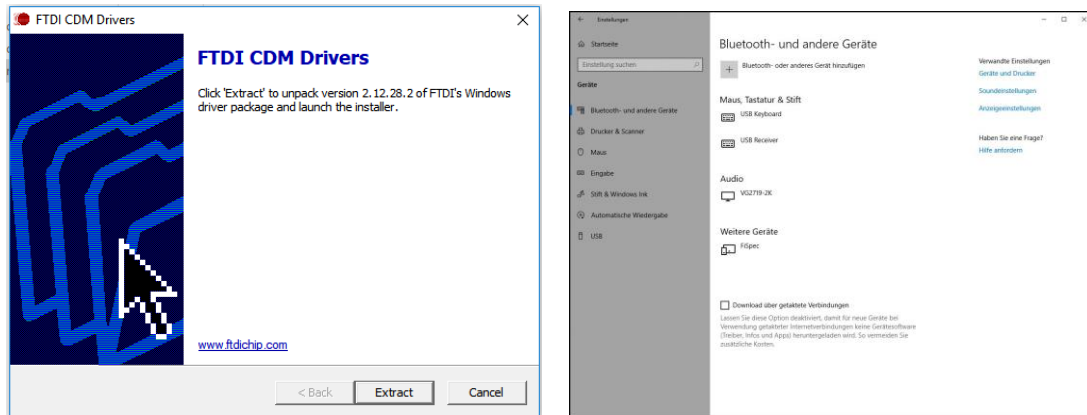


Fig. 1 FTDI driver installation window (left). Readily installed FiSpec in Windows Settings (right).

Further information can be found in the PDF files in the same directory. After successful installation of the driver, the FiSpec should reside as such in the Windows settings/ devices, as can be seen in Fig. 1 (right), and appears as a serial COM port in the device manager.

1.1.2 Labview runtime installation

BraggSens software is based on National Instruments LabView. So to use it, one has to install the fitting runtime environment. By installing

```
[...] \FiSens BraggSens 1.88 Install\Volume\ FiSens BraggSens 1.88  
install.exe
```

both the runtime environment as well as BraggSens software itself will be installed (see Fig. 2).

During the installation, a shortcut to BraggSens will be placed on the desktop.

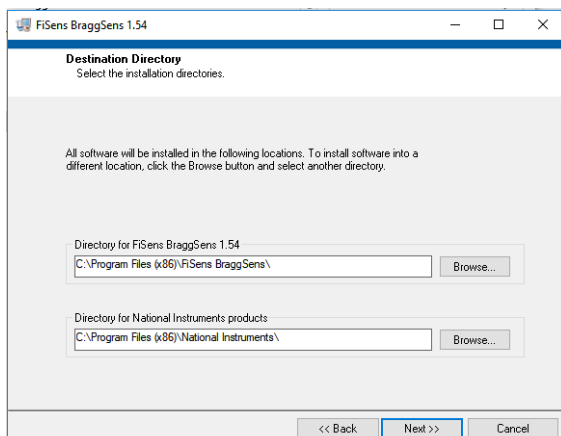


Fig. 2 LabView runtime environment installation.

1.2 File types and directory structure

When installing and using BraggSens, certain folders are created and populated in the user's "My Documents" folder. When saving or loading configuration or spectra files, the user is automatically pointed to this folders. However, other places may be used at any time. The folders created are the following:

\Documents and Settings\[user name]\My Documents\FiSens\FBG Sensor Plane Configurations

This folder contains files with *.cfg6 extension. These are binary files each comprising a complete "FBG sensor plane configuration" (for details, see chapter 2.4) array.

\Documents and Settings\[user name]\My Documents\FiSens\Software Configuration files

In this directory, the BraggSens software saves certain settings it wants to remember for its next startup.

BraggSens Last Sensor plane path.cfg

BraggSens Program settings.cfg

The "Last sensor plane path" file is updated when loading a new configuration file or when exiting the program. It is also used to pass over information to the FiSens FBG 3D Shape.

All files may be deleted without doing any harm; in this case standard values are set at the next program start.

\Documents and Settings\[user name]\My Documents\FiSens\Saved Data

This folder contains the user saved data (for details, see chapter 2.12). One correspondingly named (format: YYYY_MM_DD) sub-folder is created on every new measurement day. Inside this sub-folders, measured data is saved in either binary (Sensor plane configurations, *.cfg5) or text format (*.dat for spectra and *.txt for strain, wavelength and temperature data).

2 The FiSens BraggSens software

2.1 Quick First Steps

Once you have successfully installed the BraggSens software and connected the FBG sensor with the spectrometer, you will see a raw spectrum of the FBG array (see Fig. 3), whereby each spectral peak corresponds to a respective FBG sensor along the fiber. To quickly start first measurements, you can use the "Auto-Set Channels" Button on the left, which will automatically find all available FBG sensors within the spectrum and assign a channel to it. You can either declare the FBG as temperature or strain sensors.

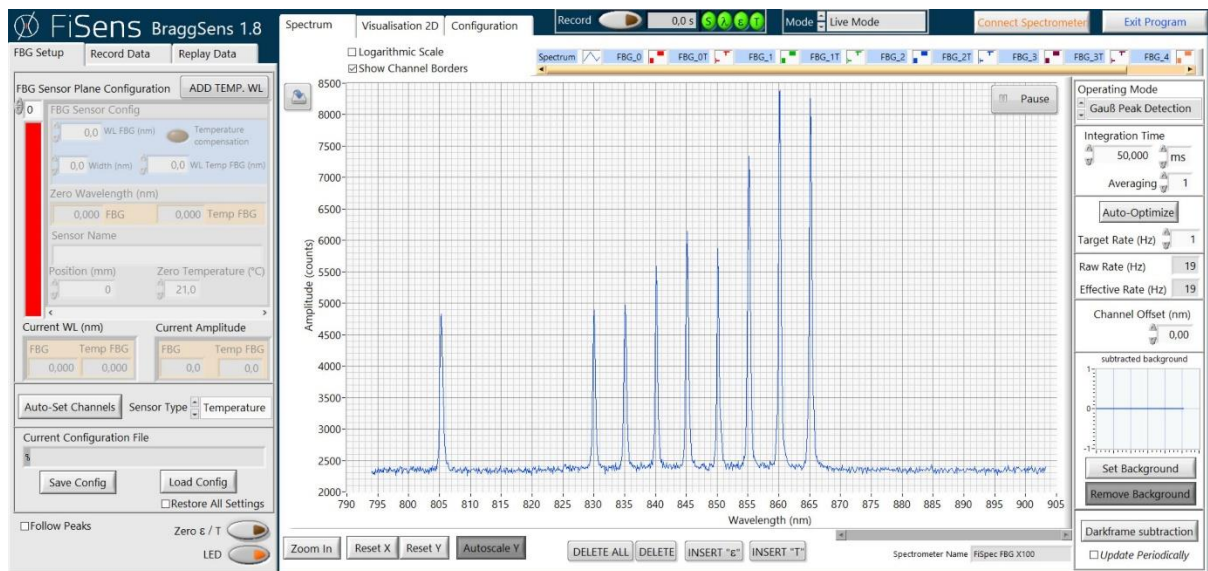


Fig. 3 BraggSens program at first start up with connected FBG array.

After each FBG signal peak has been detected (which will then look like in Fig. 5), you can switch to "Visualization 2D" tab on the top panel next to "Spectrum" (see Fig. 4). Here you will see all detected FBGs assigned as strain or temperature sensors with corresponding zero values. All FBG sensors are listed in numerical order corresponding to the 1st FBG closest to the spectrometer and the last FBG at the furthest distance from the spectrometer each having another color to differentiate (as seen on the right time graph below). You are now ready to start FBG measurements.



Fig. 4 "Visualisation 2D" plot at first start up.

2.2 Program overview

2.2.1 Connecting a spectrometer and starting the BraggSens program

The spectrometer should be plugged into a USB port providing it with sufficient electrical current (about 200mA) without the voltage dropping too much. So long cables, stacked unpowered USB hubs or the like may result in erratic behaviour.

To assure precise measurements, it is recommended to let the system thermally stabilize for about 30 minutes before doing critical measurements. If a compensation FBG is used, be it internal or external, the system is essentially stable from the first moment on.

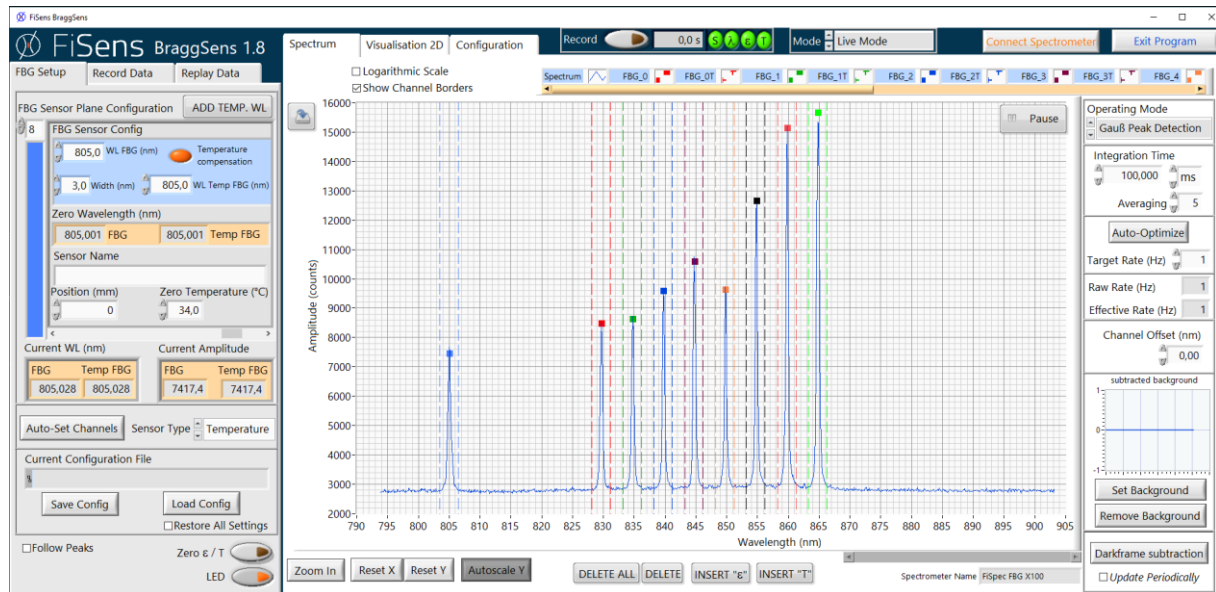


Fig. 5 Frontpanel of the FiSens BraggSens program.

When starting BraggSens, the front panel will look like in Fig. 5. In principle, BraggSens works in two selectable modes ("Live/Data Playback" switch on the upper right side): "FiSpec live mode" and "data playback". When in live mode, a spectrometer is connected and measurements can be performed. If at some time the connection to the spectrometer gets lost (for example when pulling on the USB cable), it is necessary to reconnect the system by clicking the "Connect Spectrometer" button on the right top. When switching to playback mode, the spectrometer is disconnected and the program shows the "Replay Data" panel (for details, please refer to chapter 2.14). In this mode it is possible to reconnect at any time by again clicking "Connect Spectrometer".

If the spectrometer has been found, BraggSens is started in live mode, the internal light source is switched on and the measurement starts. If however no spectrometer is connected to the computer yet or the serial driver is not installed (see chapter 1), a pop up window will tell that no device was found and the program automatically tries again every five seconds indefinitely. If clicking "Abort" or pressing the ESC key, the device search is aborted and the program enters Data playback mode.

When exiting the program, it is advised to use the "Exit Program" button on the extreme right top, as some standard values are saved and the running measurements on board of the spectrometer are then properly stopped. However, just shutting the program down does no real harm but possible difficulties at reconnection.

In rare cases after using exotic devices and drivers, Windows assigns the same COM port two times at once. This may confuse the automatic port search. In this case, go to the Windows device manager -> View -> show hidden devices (see Fig. 6). Then the currently not active serial ports are shown

(grayed out) and can be deleted. After that, the automatic COM port search should again work properly.

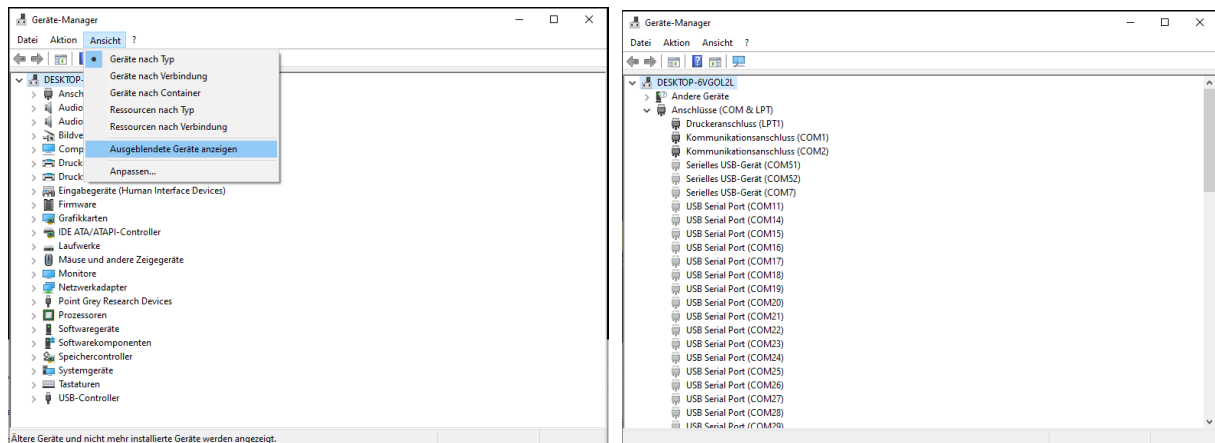


Fig. 6 Showing hidden devices in Windows device manager (left). Previously hidden COM-Ports (right).

2.2.2 Using command line parameters and multiple instances

If measurements with several FiSpec devices at the same times are to be performed, it is possible to start BraggSens multiple times when choosing different COM port. If this is not possible, please open the "FiSens BraggSens 1.81.ini" file in the same folder and add the line

```
AllowMultipleInstances=true
```

For automatically starting measurements, even with several devices, it is possible to write and start one or more batch files. The file "Example Batch file for BraggSens.bat" is delivered together with the BraggSens application and shows exemplarily how to do this.

The available command line parameters are listed in Table 2 (chapter 3.1).

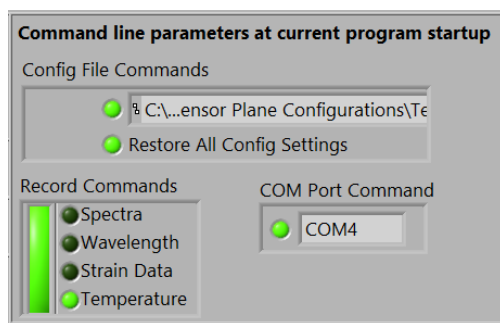


Fig. 7 Detected command line parameters.

When started with valid command line parameters, BraggSens shows an overview in the Spectrum-> Miscellaneous Settings panel (see Fig. 7): valid parameters are marked by light green dots. If at least one record command (in Fig. 7: "Temperature") has been passed to the program, the green bar is lightened.

2.2.3 Panel arrangement

As shown in Fig. 5, there is one slender panel on the left containing FBG setup / Record Data/ Replay Data sub panels, whereas on the right there are Spectrum / Visualisation 2D / Configuration panels with the main graphs.

With "LED" active, the inbuilt light source illuminates the fiber connected to the FiSpec spectrometer. The big graph in the "Spectrum" panel then shows the intensity of the signal back reflected by the FBG sensors connected. If the button "Logarithmic Scale" located above the spectrum is activated, the y-axis is shown in a logarithmic scale, normalized to the maximum value.

In "FBG Setup", the current sensor FBGs can be configured (peak wavelengths, temperature compensation and the like) to achieve correct measurement results (see chapter 2.4). If some FBGs are already defined (e.g., loaded from a formerly automatically saved config file), colored dots or crosses inside the "Spectrum" graph indicate peak maxima found in the measured signal. The controls on the right side of the spectrum are used for setting up the spectrometer (see chapter 2.3), peak search options (chapter 2.10) and background subtraction (chapter 2.9).

The "Record Data" and "Replay Data" sub panels are used for saving and retrieving measurement results to and from disk and are described further in chapters 2.12 and 2.14.

In sub-panel "Visualisation 2D" the results of the strain and temperature calculations based on peak detection of the spectrum are shown. This settings are explained in chapters 2.6 and 2.7.

The "Configuration" panel accommodates some specific settings. Among these are the settings of the "System Drift Compensation", which can compensate for the thermal drift of the measurement system itself when using either internal or external FBG sensors (see chapter 2.11). While measuring, data can be streamed over an IP based network to another program on the same computer as well as another computer at a distant position (panel "UDP Stream", see chapter 2.13).

An important role in reaching high measurement rates is the optimization of the USB port (panel "USB configuration"). The microcontroller on board of the FiSpec sends the latest spectrum or peak information every time when receiving a command to do so. At Microsoft Windows operating systems, the standard latency for USB based RS232 ports, i.e. the timeout time to wait if the buffer is not filled completely and therefore not has to be flushed yet, 16 Milliseconds. So when not changing this value, a maximum frequency of only 60 Hz is achievable. When setting this value down to about 2 or 1 ms (depending on the system), repetition rates can be much faster. This can be done by the user in the device manager. However, BraggSens is able to do it itself if started with Administrator privileges (right-click on the BraggSens icon and choose "run as administrator"). In this case, just type in the desired Latency and choose "Set Latency". BraggSens will then change the Windows Registry on its own. After restarting the program, this change will take effect.

2.2.4 Quick saving diagrams

Next to all diagrams there are buttons like the one shown in Fig. 8. When clicking on it, a file name is asked (standard value: actual time; just hit Enter key), and then the diagram is exported as both .bmp graph file and the respective measured values as .txt file.



Fig. 8 Shortcut for saving actual BraggSens diagrams.

2.3 Setting measurement parameters

On the right side of the "Spectrum" panel, all important basic settings for the measurement can be found (see Fig. 9). In "Operating Mode" it is possible to switch between "Gauß Peak Detection" (whole spectra are transmitted, and the BraggSens software searches for peaks and calculates strain and temperature values out of it) and "Onboard Peak Detect." (peaks are readily detected on the FiSpec device; only peak information is transmitted, and the shown spectrum is not updated).

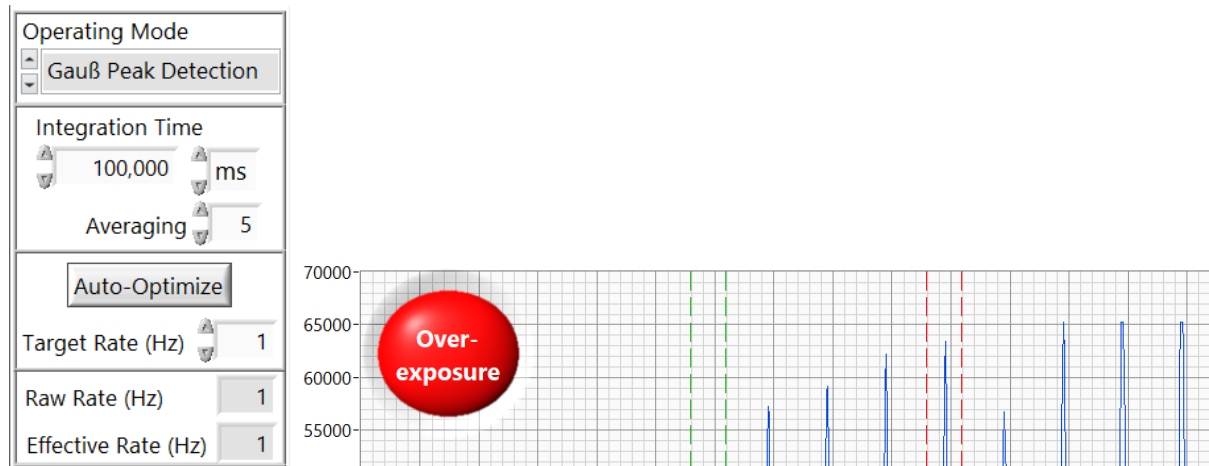


Fig. 9 Measurement settings panel (left). Overexposure warning (right).

The "Integration Time" determines how long the pixels are irradiated for each measurement before being read by the analog digital converter.

For longer integration times, the measurement frequency is roughly proportionally inverse to the integration time. At shorter integration times, data acquisition and -transmission limit the maximum measurement frequency. For example, with ideal sensors and electronics 30 μ s integration time would result in a 33 kHz rate, whereas in reality the FiSpec FBG X150 tops out at about 300 Hz when doing onboard Peak detection.

The maximum signal is about 65,000 counts, and in principal signal quality gets better with longer integration time. So it is advisable to aim for FBG peak maxima in the upper half of the intensity range.

When the sensor gets saturated caused by the exposure time being too long, a red "Overexposure"-sign appears in the left upper part of the spectrum (see Fig. 9 right; the peaks are cut off at a value of approximately 65000). When using background subtraction, the sign also seemingly may appear at lower values; in this case, the uncorrected signal itself is already saturating. Beware that in onboard peak detection mode this warning does not appear.

To further optimize the signal and reduce noise, it can be useful to average several successive spectra. This can be done by setting the "Averaging" control (Fig. 9) accordingly. The Averaging option tells the microcontroller to average as many spectra as the number indicates onboard; after that the readily processed data is sent over USB to the host computer. As a side effect this reduces the amount of data being transmitted, so at short integration times equivalent to higher frequencies than transmittable, averaging can be used to to further optimize the signal without slowing the measurement rate further.

2.3.1 Auto-optimizing settings

When clicking "Auto-Optimize" (see Fig. 9), the BraggSens program manipulates the integration time and averaging according to the "Target Rate" (Hz), starting at a medium integration time value and varying it until the peak intensities roughly reach this area. The maximum value set by the automatic is 500ms. Keep in mind that changing only the target rate value does not result in any changes; "Auto-Optimize" has to be clicked to execute this change.

With very intensive signals being present the automatic optimizer may yield a combination of integration time and averages that leads to a measurement frequency higher than originally targeted, whereas one average more would result in a measurement frequency lower than the requested one. As the algorithm is quite conservative to avoid overexposure, however, there is some signal headroom left to increase the integration time by hand; therefore it may be possible to approximate the desired frequency anyway.

2.4 Configuration of FBG sensor planes

Before measuring strain or temperature, the sensor array needs to be defined in the BraggSens program. Fig. 10 (right) shows as an example a spectrum that may appear on the screen after connecting a sensor fiber containing 16 FBGs and choosing the correct integration time.

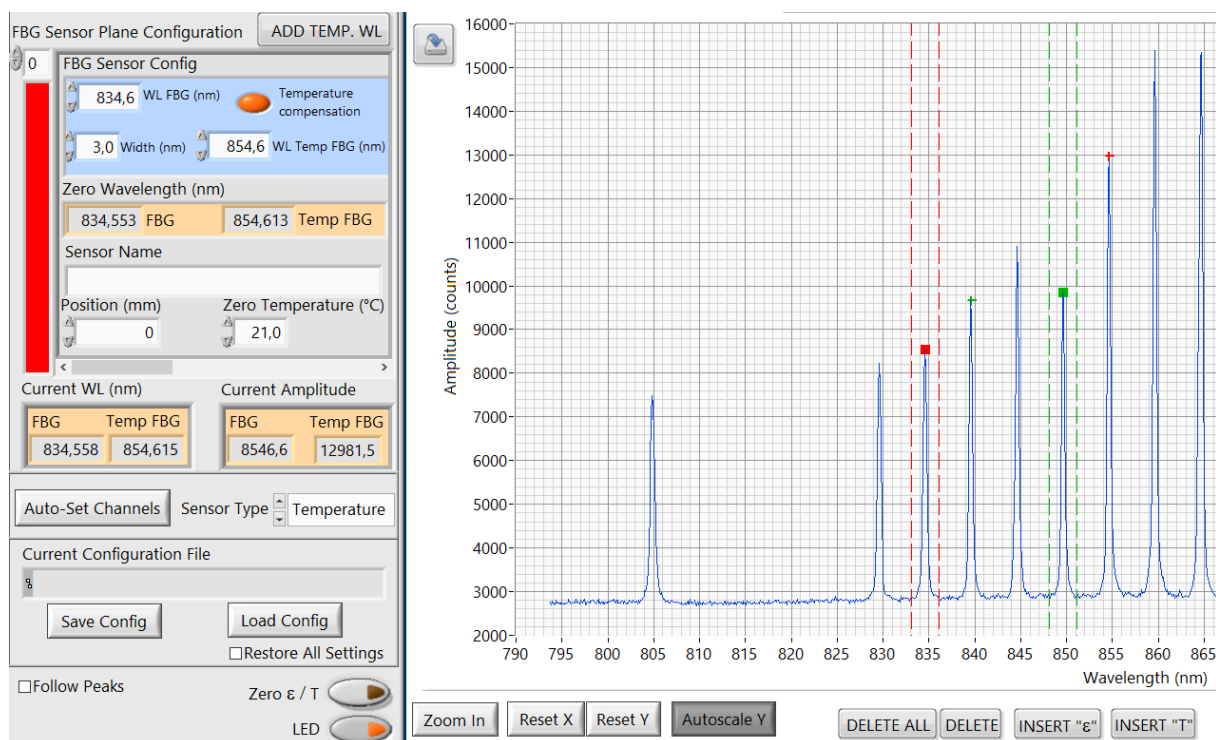


Fig. 10 FBG sensor plane configuration panel (left). Spectrum with strain FBGs (squares) and Temperature compensation FBG (cross) (right).

Each sensor is to be configured in the FBG sensor plane configuration array (Fig. 10, left). This is possible either by mouse or by directly typing numbers into the fields of the plane configuration panel.

To add an FBG, activate the "insert" button underneath the diagram (Fig. 11, left) . Now when clicking near a spectral peak, an automatic peak search around the clicked wavelength will determine its wavelength and add a new entry into the FBG sensor plane configuration array, writing the

previously found peak wavelength into "WL FBG (nm)". Furthermore, when in insert mode, a "channel width" indicator will appear on the upper left side of the spectrum. Every peak search channel added by mouse click will get the channel width displayed at the time of its creation. It is possible to change this values later directly in the "FBG sensor plane configuration" panel.

If a peak search channel already exists near the indicated area, no new entry is generated. This does not apply to temperature compensation channels described in the following paragraph, as one compensation FBG may well be used to compensate several of its neighboring strain measurement FBGs.

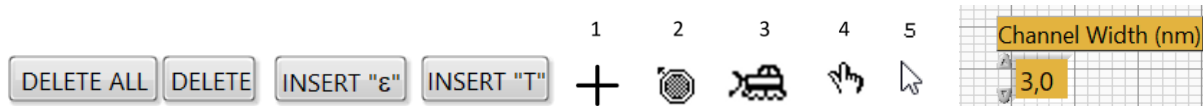


Fig. 11 Diagram peak search channel managing buttons (left). Diagram cursor types (middle): 1) Inserting new strain FBG channel. 2) Inserting Temperature FBG channel. 3) Delete peak detection channel. 4) Insert Temperature compensation FBG peak detection channel. 5) Normal (i.e. no delete/insert) mode: select sensor plane to display in "FBG Sensor Plane Configuration"; "Zoom In" mode. Peak channel width adjustment (right).

To assign a temperature compensation FBG to a particular FBG, activate the "Add Temp. WL" button on top of the "FBG Sensor Plane Configuration" section. The mouse cursor changes (see Fig. 11, Cursor 2, and the desired Temperature compensation FBG for the actually in "FBG sensor plane configuration" shown FBG can be selected. This peak position now appears at the "WL Temp FBG (nm)" entry of the avtice FBG.

In the example in Fig. 10, FBG sensor plane number 1 (red square dot, 834.6 nm) was selected; after that a temperature FBG (red cross, 854.8 nm) was assigned. So in future when activating "Temperature compensation", the 834.6 nm FBG will be temperature compensated by the Temp FBG at 854.8nm.

When neither Delete nor Insert buttons are active, the mouse can be used to simply click on a peak dot; the FBG sensor plane configuration panel will then change to the associated sensor plane. The bar at the underside of the panel can also be used to change between the array contents. Switching between different sensor planes does not affect measurements.

The currently measured peak position/amplitude data is shown in the yellow area.

In the configuration panel, "Sensor Name" and "Position" are for informational purposes only for normal sensor fibers; they don't affect measurement results. The sensor name is also used for naming the graph legend.

2.5 Auto-set channels

Instead of inserting peak channels by oneself, in most cases this can be done automatically. When clicking the button "Auto-set Channels" (in "FBG Setup" panel, see Fig. 10), the BraggSens program searches the current spectrum for FBG peaks, deletes the FBG sensor plane and instead adds the newly found data, depending on the "Sensor Type" setting.

Keep in mind that no peaks are searched in the spectral area around the reference FBGs. If these shall also be detected, they have to be added manually like described in chapter 2.4.

If in some cases the automatic detection fails because of stray light, too high contrast or side lobes, it is possible to modify the detection sensitivity factor. It can be found in the "Configuration"-

>"Miscellaneous Settings" panel (see Fig. 12). In general: if the factor is higher, only the more intensive peaks will be found. So if there are too less peaks found, choose a lower factor.

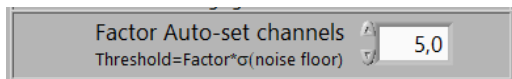


Fig. 12 Settings for auto-set channel function.

2.6 Measuring strain

After the sensor configuration has been set the measurement can start. Ensure that all sensors are at their rest position and press "Zero strain" (Fig. 10, left). The current wavelength values of the FBGs and their respective Temperature FBGs will then be transferred into the FBG sensor plane configuration array (yellowish "Zero wavelength (nm)" compartment). Future strain measurements now base on the difference to this zero wavelength values; if they result in longer wavelengths, positive strain is detected and vice versa.

If "Temperature compensation" (Fig. 10, left) of a certain FBG is activated, the zero wavelength of this FBG saved when pressing "Zero strain" is supposed to coincide to the "Zero Temperature" value dialled in into the sensor configuration array. To get precise temperature values, this zero temperature has to be adjusted by hand to match the temperature at this specific FBG at the time of zeroing. If only drift compensation is required, the standard value (21 °C) can be chosen.

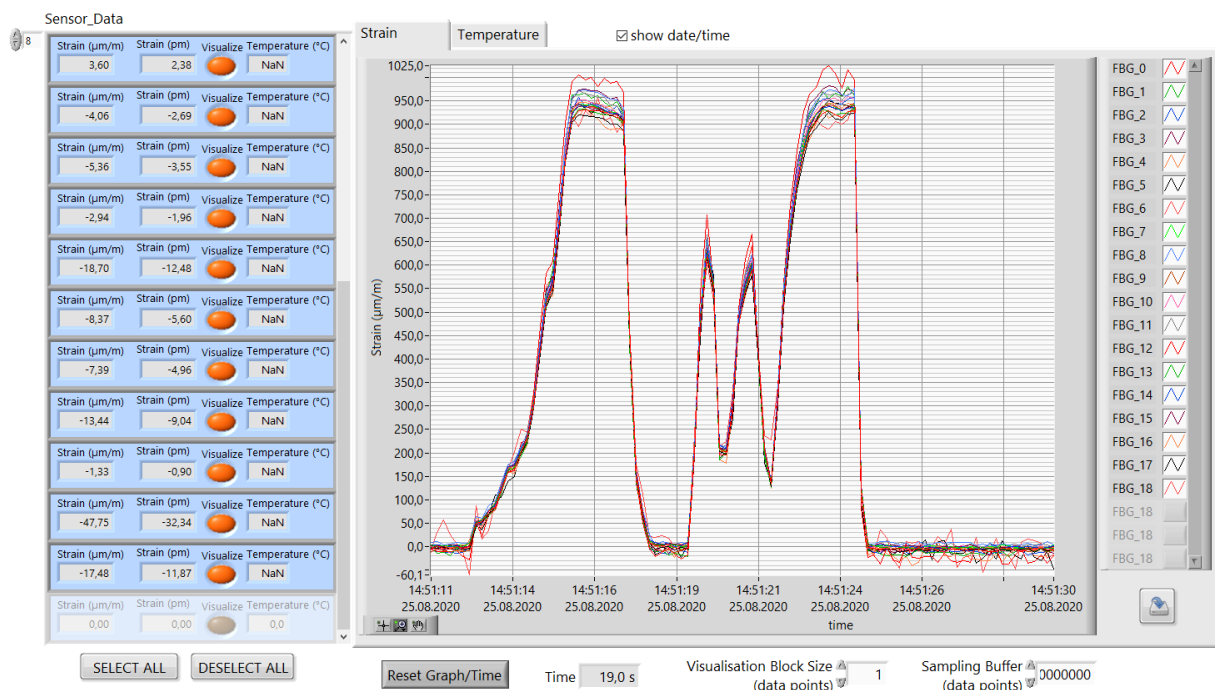


Fig. 13 Visualisation 2D section.

In the "Visualisation 2D" section (see Fig. 13, Array "Sensor_Data"), the current measurement results of the different sensor planes are shown: Strain is noted in $\mu\text{m/m}$ as well as the wavelength difference relative to the respective zero wavelength in picometers. To minimize processor load, visualisation of the measurement results is disabled by default. In Sensor_Data visualisation can be chosen for every single FBG; if enabled, the said sensor's results are shown in real time in the "Strain" or "Temperature" graphs (Fig. 13, right). Underneath the Sensor_Data section, there are "Select All" and "Deselect All" buttons. When using them, it is not needed to activate every single channel manually. When the "Auto-set channels" function is used, all newly found channels are set active automatically.

Beware that data is only displayed if their respective "visualize" indicator is set active!

Clicking "Reset Graph/Time" resets the graph, for example after setting zero strain. For high measurement frequencies with onboard peak detection it can be useful to not update the graph every time new data comes in, but rather to accumulate the data and refresh the diagram periodically. This can be done by the "Visualisation Block Size" setting.

2.7 Measuring Temperature

When inserting a temperature FBG via the "Insert 'T'" button, the same FBG wavelength is written in both strain FBG and temperature compensation FBG wavelength, so that both wavelengths in the "FBG Sensor Config" array are the same. The resulting strain data then has to be ignored, but the temperature value is valid. After initiating a "Zero Strain" process, the actual temperature of the temperature FBG is then shown in the "Visualisation 2D" section (see Fig. 13, Array "Sensor_Data"). The temporal evolution of this value can be seen in the "Temperature" diagram (behind the "Strain" graph) when the respective "Temperature compensation" button in the "Sensor_Data" array is active. This values can be saved to disk like described in chapter 2.12.

2.8 "Follow Peaks" option and Channel Offset value

When measuring stronger forces or great temperature differences, the peak wavelength changes significantly (roughly 0.6nm wavelength change at 1000 μ m/m strain). If this changes gets the peak position to wander out of the defined peak position detection channel, the peak detection searches for another maximum inside the now abandoned channel and reports erroneous values like can be seen in Fig. 14 a).

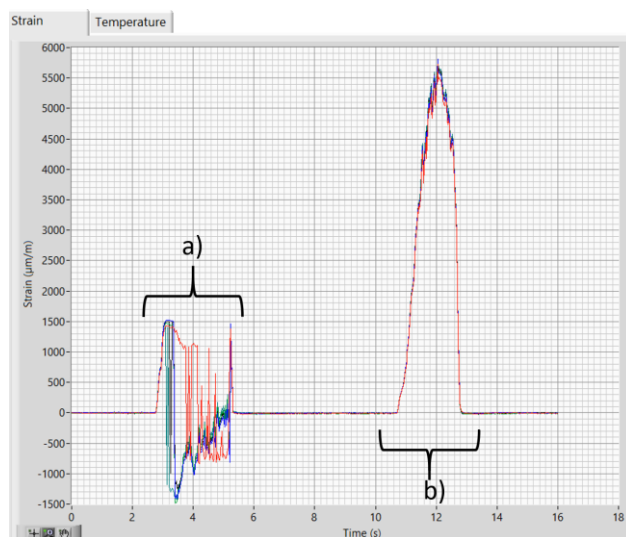


Fig. 14 Measured strain values while pulling the fiber hard with a) Follow Peaks disabled and b) Follow Peaks enabled.

Enabling Follow Peaks automatically centers each channel around the associated measured peak position each time a new value is measured. So the peak detection channel steadily follows the peak position (see Fig. 14 b)) as long as the repetition rate is high enough, i.e. if the peak is not momentarily jumping out of range.

This function works both in onboard peak detection mode and in Gauß Peak Detection/Peak Detection operating mode. When disabling Follow Peaks, the original channel wavelength values are restored.



Fig. 15 Channel offset adjustment window (BraggSens, right side)

If the temperature or strain value foreseeable changes only in one direction, for example only higher temperatures than room temperature or only strain, but no compression is expected, and if the FBGs are quite near to each other so that no wide channels can be established without measuring part of the slopes of neighbored FBGs, it is sensible to decenter the channels in the direction of the expected changes instead of centering it around the zero wavelength. Such a channel offset can be set globally (for all channels alike) by the "Channel Offset" number on the right side of the "Spektrum" panel (see Fig. 15).

2.9 Noise / background reduction options

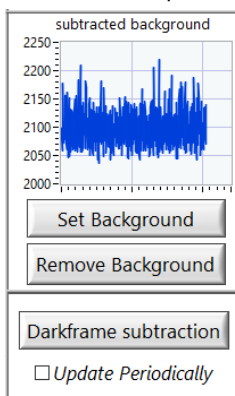


Fig. 16 Noise reduction settings panel.

In general, signals measured by CMOS sensors suffer from readout noise, thermal noise and photon noise. Furthermore, there may be a spectrally varying background for example caused by ambient light (for spectrometer applications) or by back reflections of the inbuilt FBG light source (when measuring FBG sensors), whose intensity is constant over time.

At short exposure times, readout noise mainly caused by the electronics dominates the noise floor. This signal is largely time and temperature independent and is taken care of on board by the microcontroller. This results in an offset of about 2000 counts.

Constant ambient background signal and thermal noise background may be reduced by two methods, here called "onboard noise reduction" and "background correction", that are made available to the user by the noise reduction panel settings shown in Fig. 16. They are described in the following sub sections.

2.9.1 Darkframe subtraction (onboard)

At long exposures (about 200 milliseconds and up), CMOS sensors exhibit mild to significant dark noise caused by thermal electrons, which is proportional to the exposure time. Furthermore, this noise may be slightly different for different pixels ("hot pixels") and changes with aging and sensor

temperature. To simplify handling, a five seconds room temperature black frame is already saved in the microcontroller's non-volatile flash memory in the factory. When "Onboard NR" is activated, this black frame is automatically subtracted from the measured signal. It is automatically scaled to the current exposure time and therefore should equalize the noise pattern quite well.

In general, the onboard NR provides a convenient way to quickly improve the measured spectrum at longer exposure times without the hassle of taking a background correction frame. If, after some time, at changed temperatures or with exposure times being significantly longer than five seconds, the saved dark frame does not match the actual thermal noise well anymore, or if hot pixels are persisting and constantly visible while using the onboard NR, a new dark spectrum may be saved to the flash memory by the "FiSens FiSpec Configuration" utility. In this case, please contact FiSens GmbH for further advice. Using automatic periodic darkframe update (see chapter 2.9.2) will also solve that problem.

2.9.2 Automatic periodic darkframe update

Especially at higher device temperatures the thermal sensor noise will significantly increase and thus impair the quality of the peak finding algorithm. In this case, it is advisable not to rely on the previously (at room temperature) measured and saved 5 second dark spectrum, but to in between two measurements measure the real dark spectrum by momentary switching off the light source for this time. This has been automated in FiSpec firmware and can be chosen as an option of the darkframe subtraction function.

If "Update periodically" is ticked in the BraggSens program (see Fig. 16), darkframe subtraction does not anymore use the factory saved 5 seconds room temperature darkframe, but instead the above described periodically measured real dark spectrum. To avoid increased noise levels, the darkframe is smoothed by a low pass filter function over time, by which a new spectrum contributes only to a certain fraction to the finally used darkframe:

$$\text{darkframe}_{\text{new}} = \text{darkframe}_{\text{old}} * (100 - \text{filter_value}) + \text{darkframe}_{\text{measured}} * \text{filter_value}$$

$\text{darkframe}_{\text{new}}$ = resulting darkframe after low pass filtering

$\text{darkframe}_{\text{measured}}$ = just measured spectrum (with LED switched off)

$\text{darkframe}_{\text{old}}$ = darkframe after last measurement

filter_value = low pass "frequency"

$\text{filter_value} = 1 \dots 100$

These values are tuneable in the "Configuration" -> "Miscellaneous Settings" panel (see Fig. 17).

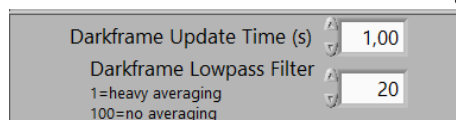


Fig. 17 Parameters for periodical background subtractions. Update time: 0.02s (50Hz) ... 40s.

The effective measurement rate decreases with activated automatic darkframe update, since after every "darkframe update time" a measured frame is used internally exclusively for this purpose instead of being transferred to the host computer.

If the integration time is longer than the update time, the FiSpec will simply wait with the dark frame measurement until the current measurement is done; in this case, the measurement rate drops to half compared to measurements without the automatic dark frame compensation.

Keep in mind that dark frame compensation has to be active for the automatic darkframe update to show any effect!

2.9.3 Background correction

When the measured light spectrum contains a constant background signal, for example backreflections of the broadband SLED light source on cleaved fiber ends or fiber couplers, ambient light, or, like explained before, excessive thermal noise because of very long integration times, it is advisable to use the unspecific "Remove background" (Fig. 18) function. To this end, as a first step it is necessary to measure the unwanted signal itself without any of the wanted one. How to achieve this depends on the actual situation; in case of FBG measurements it is useful to disconnect the FBG sensor with the light source still being enabled. Optimally, the integration time is the same as in the later measurements. This spectrum is being temporally saved to the computer's RAM by clicking the "Set background" button until the next time a background is set or until quitting the program.

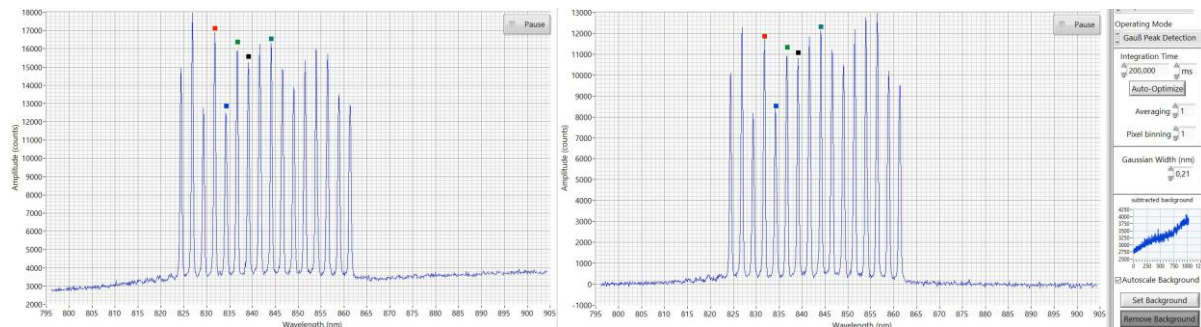


Fig. 18 Comparison of raw (left) and background corrected spectrum.

In Fig. 18, the uncorrected spectrum of an X100 (left graph) shows a broadband background; since the noise floor is normally around 2000 counts, everything above (except the FBG reflections) is unwanted signal that may affect the measurement. The small graph on the right ("subtracted background") shows the spectrum (x-Axis shows pixel numbers instead of wavelengths) that was measured and temporally saved with no FBG attached to the system. The middle graph shows the FBG spectrum resulting out of background removal; the background is now near zero.

A feature to be noted is the "Autoscale Background" button (panel "Configuration"-> "Miscellaneous settings"). If this checkbox is ticked, the background signal is scaled automatically in respect to the current integration time, so that no further background measurements are necessary when changing integration time. Note however, that this scaling naturally has its limitations when the actual integration time is significantly different to the one used during the background measurement, especially when using much longer integration times than before.

This background correction may be used on its own or in combination with the onboard darkframe subtraction.

2.10 Peak search options

When measuring FBG sensors, correct peak recognition is crucial. In the BraggSens program, the "Operating Mode" switch offers two different ways with specific benefits and drawbacks:

	repetition rate	processor load	shows actual spectrum	number of channels
Onboard Peak Detection	fast	low	no	32
Gauß Peak Detection	slower	high	yes	"∞"

Table 1 Characteristics of peak search options.

These are explained further in the next subchapters. When the program starts, Gauß Peak Detection is enabled by default.

2.10.1 Onboard Peak Detection

Measuring systems of the FiSpec family are able to do a signal analysis on board of the spectrometer itself. In this case, only readily calculated results (peak wavelength and intensity) are transmitted to the host computer and therefore the amount of transmitted data is significantly reduced. So the measurement rate achievable is the highest of all three peak detection options.

Because of hardware restrictions, a maximum of 32 peak channels can be defined.

In this mode, the actual measured peak positions are shown in real time, whilst the last measured complete spectrum is shown for illustrational purposes as a still frame in the background.

In onboard peak detection, two different algorithms can be chosen (panel "Configuration" -> "Miscellaneous Settings", see Fig. 19): "center of gravity" and "derivative". With significant sidelobes and spectrally tightly spaced FBGs it may be better to choose the derivative mode. Note, however, that this one results in more noise than the center of gravity method, which is therefore to be preferred in most cases.

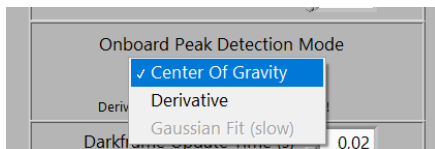


Fig. 19 Onboard peak detection modes.

2.10.2 Gauß Peak Detection

Apodized FBG sensors feature a reflective spectrum resembling a Gauß distribution. Fitting a Gauß curve to the measured spectrum delivers optimal results in most cases and reduces noise roughly by a factor of two. There is, however, a penalty to pay: this sort of fitting is mathematically more complex than a simple search for the maximum value, derivative or center of gravity calculations. When using FiSpec spectrometers, the Gauß peak search is done by the BraggSens program on the host computer, so the measurement rate depends on the computing power of the host computer and slows down according to the number of peaks search channels being active.

In principal, the number of peak search channels is limited only by the capacities of the host computer.

When using Gauß peak detection mode, the "gaussian width (nm)" setting (panel "Configuration" -> "Miscellaneous settings", see Fig. 20) can be adjusted. This value tells the fitting algorithm what peak width (FWHM, full width at half maximum) to expect. It is recommended to choose a value that results in halfway correct peak amplitudes (colored dots at the maximum height of the peak), although the strain measurement is quite tolerant because of it depending solely on peak positions. However, the better this value coincides with the actual peak width the faster the Gauß fit converges, so when using many peak search channels at once it is advisable to optimize this value.

Another option in the Gaussian Width section is "update automatically when selecting new sensor channels". When activated, the peak search algorithm tries to optimize the FWHM of the fitted Gauß peak when adding new channels by mouse click or by Auto-set channels. Afterwards the best fitting FWHM is inserted here und since then used as a standard value for all Gauß fits during measurements. Beware that in the rare case of FBG sensors with very different widths in one fiber this could cause problems.

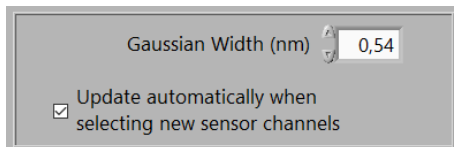


Fig. 20 Settings for Gaussian peak search algorithm.

2.11 System drift compensation

When an inbuilt reference FBG is present, the option "Use Internal Reference FBG for Drift Compensation" is selectable (see Fig. 21). In this case, all parameters in the "Reference FBG Properties" box are set automatically based on the information saved in the spectrometer itself. If "Enable Drift Compensation" is then activated, the measurement system will continuously perform automatic peak searches in the background, smooth the result by low pass filtering and calculate the resulting drift compensation.

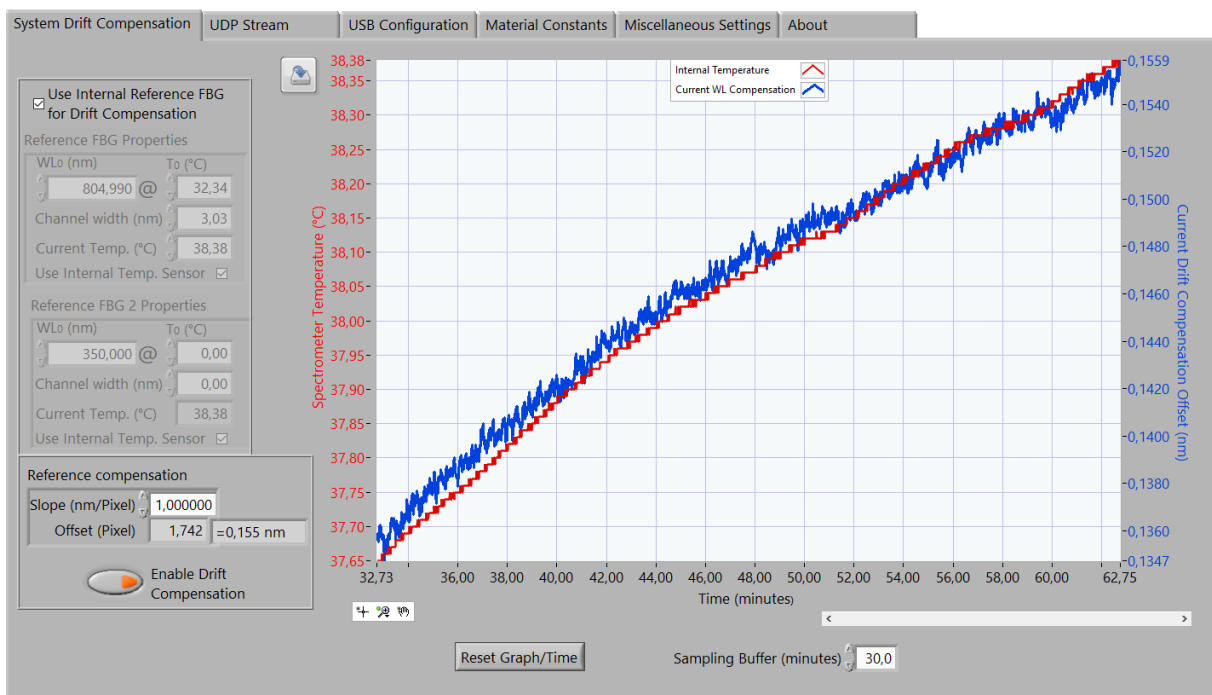
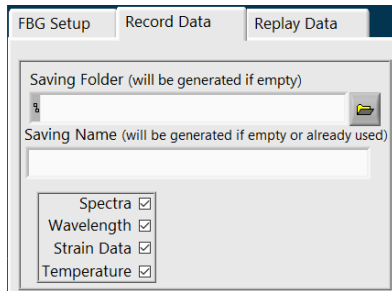


Fig. 21 Reference FBG drift compensation panel.

When no built in reference FBG is present it is still possible to use this function as a global drift compensation. In this case, an arbitrary external FBG of known temperature and WL_0/T_0 parameters can be used. After entering the appropriate values into the "Reference FBG Properties" field, drift compensation can be switched on and works just like with a built in reference FBG. However, changes in temperature have to be actualized by hand. If for example the reference FBG is operated at stable room temperature, the spectrometer may already be quite satisfactory compensated.

2.12 Recording measured data

In "FiSpec Live mode" it is possible to save the currently measured data to the hard disk. The respective controls are located in the "Record Data" panel (see Fig. 22). As a default data will be saved as text files (for file format details see chapter 3.3) to the directories described in chapter 1.2.



Every time "Record current spectra/Strain data" is activated, a new saving name will automatically be generated if there is no file name given or the given name is already in use. The "Spectra / Wavelength / Strain Data / Temperature" checkboxes each lead to the creation of an equivalent data file. If no checkboxes are activated, recording will not start. On the other hand the recording function is not influenced by whether "Visualize" in the "Sensor_Data" array is active or not.

Fig. 22 Saving panel.

Note that the recording time starts at zero every time the recording starts, and time data inside of the saved files is always referring to it regardless of when or if "Spectra / Wavelength / Strain Data / Temperature" is activated afterwards. This timer is independent of the "Visualisation 2D" timer and stops as soon recording is deactivated.



Fig. 23 Recording shortcuts.

For convenience, the "Spectra / Wavelength / Strain Data / Temperature" checkboxes are repeated on top of the program (see Fig. 23). Clicking "S" activates the "Spectra" checkbox, clicking "λ" activates the "Wavelength" checkbox, and so forth. So in one glance it is possible to know what sort of data is saved when activating the "Record" button.

2.13 UDP streaming of measured data

The Fisens BraggSens program provides the opportunity to send readily processed strain or temperature data as well as receiving instructions via UDP (User Datagram Protocol) to or from another program on the same computer or via an IP based network. Note that this protocol is not failsafe, as data packets may get lost or overtake each other temporally without further notice, especially when traveling long distances over different paths.

The UDP settings are located at a sub-panel inside of the "Configuration" panel (see Fig. 24). If the remote program is located on the same computer, type in "localhost" for both local and remote IP address. The local IP address can be left at "localhost" in most cases. If the local computer has more than one network adapters it may be necessary to further specify the local IP address BraggSens

listens on to get remote instructions. If the remote program resides on

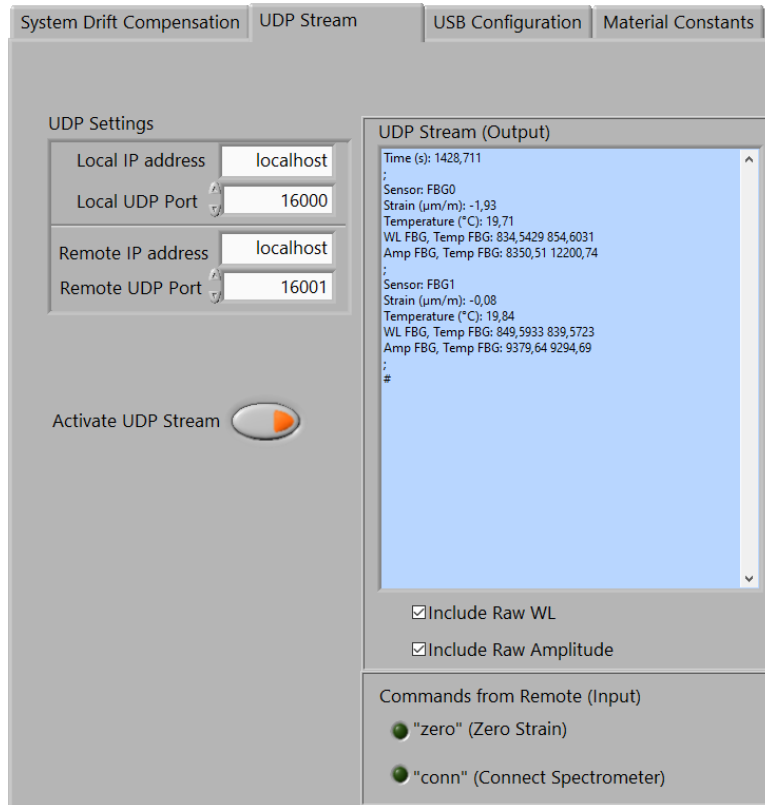


Fig. 24 UDP stream settings panel

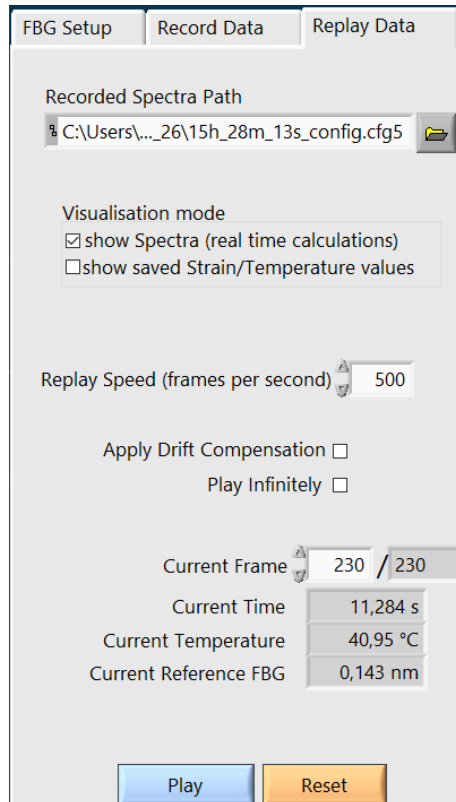
another computer, the IP address of this computer has to be known and typed in the related panel "Remote IP Address" field. By default, ports are set to 16,000 (BraggSens program) and 16,001 (remote program); they can be changed if any collisions with other programs occur. Any change in the settings will be immediately saved on disk as described in chapter 1.2.

UDP streaming of measured data and remote control of the BraggSens software is activated by clicking the "Activate UDP Stream" button. When using UDP streaming for the first time, a Windows Firewall warning may appear. By clicking "Allow access", data can be exchanged with other programs on the computer or over network connections. Now the data sent by the BraggSens program can be seen in real time in the "UDP stream (output)" window. The remote program on its part can send "Zero Strain" and "Connect Spectrometer" instructions to the BraggSens program; the respective indicators light up shortly when incoming instructions are recognized.

2.14 Replay of saved data

All data measured and saved with the BraggSens program can be visualized in BraggSens itself, whereas temperature or strain data files may also be analyzed with other programs, for example by using a spreadsheet program or a standard text editor.

The file to be displayed has to be chosen by clicking the folder symbol on the right side of the "Recorded Spectra Path" (see Fig. 25) field. When recording, a .cfg5 is saved along with the data. So the desired file has to be chosen. As a standard, the user is led to the ...\\My Documents\\FiSens\\Saved



Data path described in chapter 1.2; the data files are found in sub directories named by the measurement date.

By now clicking "Play" (see Fig. 25), the program terminates the connection to the spectrometer and uses the central "Spectrum" graph for displaying saved measured data. The data are rolled through automatically with a selectable frame rate ("Replay Speed" in Fig. 25). If the user wants to view certain single spectra, he can stop the automatic visualisation and manually select a "Current Frame" number.

The data can now also be visualized in the usual "Visualisation 2D" graphs and can be treated as if it was a real spectrometer measuring, for example changing the sensor plane configuration array, zeroing strain and so on. The only peak search option available in this mode is "Gauß Peak Detection". When choosing "Include Saved Configuration", the original sensor plane configuration used at at time of the recording is loaded. Furthermore it is possible to apply the measured drift compensation by ticking the respective box just above the Play/Reset buttons.

Fig. 25 Replay Data panel.

If "show saved Strain/Temperature values" is activated, the data of the recorded strain and temperature values is directly visualized in the "Visualisation 2D" panel without any further calculations like peak detection, background correction or drift compensation. Especially in longer measurements with thousands of samples this mode is considerably faster.

3 BraggSens communication protocol and file format

3.1 BraggSens command line instructions

Like described in chapter 2.2.2, it is possible to use multiple instances of BraggSens if more than one FiSpec is available. Thus it is possible to e.g. create several batch files to control multiple FiSpec at the same time.

In Table 2, some command line parameters are given that can be used to tailor the startup behavior of BraggSens.

Command line instructions (BraggSens program)	
/COMx	Choose FiSpec located on COM-Port x on startup
/CONF:x.cfg4	loads config file x.cfg4 on startup
/restoreAllCgfSettings	restore all setting from config file at startup
/recSpectra	records spectra at startup
/recTemp	records temperature at startup
/recStrain	records strain at startup
/recWL	records raw peak wavelength at startup

Table 2 Command line instruction set for BraggSens program.

3.2 BraggSens UDP communication

When sending data to a remote program, data is transmitted in string format like shown in the following example for two FBG sensors:

```
Time (s): 30,215
;
Sensor:   FBG0
Strain (µm/m): 75,00
Temperature (°C): 13,97
WL FBG, Temp FBG: 847,7092 869,3388
Amp FBG, Temp FBG: 4581,15 2786,81
;
Sensor:   FBG1
Strain (µm/m): -2,98
Temperature (°C): NaN
WL FBG, Temp FBG: 852,6447 0,0000
Amp FBG, Temp FBG: 4452,99 0,00
;
#
```

In the first line, the time since the last "Reset Graph/Time" is noted. TAB is used as a spacer between ":" and the number. Depending on the language settings of the sender's operating system, the decimal point is either "," or ".".

Following is one paragraph for each sensor. If there are no meaningful values present, for example if the sensor is not temperature compensated (like FBG1 in the example shown above) or the system is not yet strain zeroed, "NaN" is printed instead of a number. TAB is also used as a spacer in this sections. The end of a time frame is marked by "#\r\n".

Remote programs can control the BraggSens program by sending short UDP strings (see Table 3). No termination characters are necessary because the whole received string is searched for known instructions. To date there are two instructions possible:

UDP instructions (BraggSens program)	
zero	Initiates "zero wavelength" processs
conn	Initiates reconnection of spectrometer

Table 3 UDP instruction set for BraggSens program.

zero

This is equivalent to clicking "Zero Wavelength" in the BraggSens program.

conn

This instruction activates the "Connect Spectrometer" button in the BraggSens program.

3.3 BraggSens file format

When recording spectra, temperature and strain values, files are saved by default in the in chapter 1.2 described directories. All data files consist of plain ASCII characters; data values are separated by TAB characters. Every line ends with line feed character \n. The decimal point format follows the standard decimal separator format of the operating system the files were saved. Since version 1.54, all files consist of a header, which offers information about the current spectrometer settings at the beginning of the measurement. If some parameter is changed while measuring, it will not change the file header.

3.3.1 Format of spectra files

Spectra file names are always [filename]_spectra.dat. The header consists of four lines:

Line 1) Information about program version and Data type, for example

```
FiSens BraggSens ver. 1.54 (C) 09/2019; SpectraData (counts)
```

Line 2) Information about file name, spectrometer used, firmware, measurement settings. For example:

```
Filename:C:\Users\[Username]\Documents\FiSens\Saved Data\2019_09_18\
test_spectra.dat; SpectrometerName: FiSpec FBG X100; SerialNumber:
10020016; FirmwareVersion: 6.6; IntegrationTime: 50000µs; Averaging:
1; OperatingMode: Gauß Peak Detection; PixelBinning: 1;
GaussianWidth: 0,20;
```

Line 3) Description of the following data format:

```
Tab delimited data. First line contains wavelengths: 0 / 0 / 0 /
Pixel_0(nm) / Pixel_1(nm) / Pixel_2(nm) / ...
```

Line 4) More format description:

```
Rows: time(s) / system temperature (°C) / system drift compensation
(nm) / Intensity_Pixel_0 (counts) / Intensity_Pixel_1 (counts) /
Intensity_Pixel_2 (counts) / ...
```

Line 5) The first line of data consists of three times a zero to align the wavelength numbers to the associated intensity values. After that follow the wavelengths (nm) for each saved pixel. For example:

0,000 0,000 0,000 780,331 780,413 780,494 780,575 and so on

Line 6) This and every following line consists of the following numbers: measurement time (s), internal system temperature (°C), actual system drift (nm), followed by the intensity of the consecutive pixels. For example, the spectrum 0.414 s after clicking "Record Current Spectra/Strain data ", at 30.38 °C system temperature and with activated compensation (0.012 nm) looks like

0,414 30,380 0,012 2050,000 1975,000 1984,000 2033,000 and so on

3.3.2 Format of strain and temperature files

Both strain and temperature files follow the same structure, with the first line being slightly different. File names are [filename]_strain.txt and [filename]_temperature.txt respectively. The header consists of four lines:

Line 1) Information about program version and Data type, for example

FiSens BraggSens ver. 1.54 (C) 09/2019; TemperatureData (°C)
or
FiSens BraggSens ver. 1.54 (C) 09/2019; StrainData (µm/m)

Line 2) Information about file name, spectrometer used, firmware, measurement settings, like described in the spectra files. For example:

Filename:C:\Users\[Username]\Documents\FiSens\Saved Data\2019_09_18\
test_spectra.dat; SpectrometerName: FiSpec FBG X100; SerialNumber:
10020016; FirmwareVersion: 6.6; IntegrationTime: 50000µs; Averaging:
1; OperatingMode: Gauß Peak Detection; PixelBinning: 1;
GaussianWidth: 0,20;

Line 3) Description of the following data format:

Tab delimited data.

Line 4) Name of the tab delimited data rows following from line 5 on, for example:

time (s) System temperature (°C) System drift compensation (°C)
FBG 0 FBG 1 FBG 2 FBG 3 and so on.

If the sensor FBG was given a name in the "FBG Sensor Plane Configuration" array, this name will show up instead of the generic "FBG x" shown above.

Line 5) This and every following line consists of the following numbers: measurement time (s), internal system temperature (°C), actual system drift (nm), followed by the temperature measured for the respective temperature compensation FBG. For example, the temperature values 0.414 s after clicking "Record Current Spectra/Strain data ", at 30.38 °C system temperature and with activated drift compensation (0.012 nm) looks like

0,414 30,380 0,012 21,163 20,678 NaN 21,506 and so on

Note that "NaN" is printed instead of a number if the temperature compensation of a sensor plane is not active or if no zeroing has taken place.

4 Changelogs

4.1 FiSpec firmware changelog

v. 6.4

- onboard "follow peak" function added.
- fixed corrupt spectra while changing integration time

v. 6.5

- added internal reference FBG measurement
- added reference compensation

v. 6.6

- changed "LED" command; LED current is fixed now.
- optimized reference compensation

v. 6.7

- optimized hardware parameters

v. 6.8

- changed internal reference compensation algorithm
- exchanged current wavelength compensation number by measured reference FBG wavelength in transmitted data. As both versions use the same 32bit number, there is no need to change data readout unless this specific values was used before.
- changed thermoelastic constant from $8.2E-6$ to $8.65E-6$

v 6.9

- increased number of onboard channels from 24 to 32
- optimized channel border resolution
- added onboard FBG calculations (strain, temperature, zeroing)
- `P>` command now initiates transmission of either wavelength/amplitude like before (standard mode) or strain/temperature (in onboard calculation mode)
- optional external UART: Baudrate can be set
- optional external UART: amount of transmitted data can be chosen (nothing, only basic information, peak information, complete spectra). USB is still sending in parallel to the UART.
- streaming mode added: it is now possible to endlessly send values as soon as they are measured (and previous data transmission is completed) without the need of initiating this by `s>` and `P>` commands of the host computer
- in streaming mode, the microcontroller will wait until transmission of both UART and USB is finished
- eliminated the transmission of one supernumerous channel (containing meaningless numbers) between the results of the last peak detection channel and the temperature/reference FBG wavelength information in the `P>` command answer.
- added autostart switch, either immediately starting data streaming or just switching light source (for warm up) and internal measurements on after connecting to power source
- enabled to save current state (onboard calculation mode, onboard calculation channel details, zero values, UART settings, streaming mode, autostart mode) to microcontroller's flash memory. Beware of the maximum number of write processes!

v 7.0

- added center-of-gravity onboard peak detection
- increased internal temperature sensor update frequency

v 7.1

- supports multi-fiber FiSpec systems
- pixel binning removed
- added periodic darkframe updates
- changed standard value of maximum follow peak value (before: $0.4 \times \text{channel width}$; now: $0.25 \times$)
- supports multiplexed systems
- readout of set channel border values possible
- restricted channel width to 200 pixels
- supports second reference FBG

v 7.2

- internal temperature sensor value averaging optimized
- compensation: introduced slope value transmission. $\text{transmission} = (\text{value} - 1) \times 1E6$

v 8.0

- optimized periodic darkframe updates
- future firmware updates via USB possible

v 8.1

- optimized reference wavelength smoothening
- new experimental peak detection mode: spectral FIR-filtering
- fixed: from version 7.1 to 8.0 maximum follow peak channel shift value was not used

v 8.2

- in active reference compensation mode/deactivated follow peak mode: channel borders now shift according to reference FBG compensation offset
- fixed: microcontroller was no longer accessible after receiving more than 30 characters without termination character ">"

v 8.3

- thermoelastic constants (separate values for reference FBGs and sensor FBGs possible) and optoelastic constant can now be changed via serial commands.
- further smoothening of reference FBG signal

v 8.4

- in follow peak mode: channel width internally reduced to 60%, to prevent neighboring peaks interfering during significant temperature/strain changes. After switching follow peak mode off, the original channel width is being restored.
- reference FBG correction equation changed
- fixed: follow peak function (in ver. 8.3: not permanently active when desired so)
- some stability fixes
- automatically detecting channels in reference FBG channels range. Since now: when zeroing the channels, T_0 is set to the device temperature.

-follow peak function optimized: the channel borders will follow the peak only when the signal quality is sufficient (preventing erroneous channel changes e.g. when no sensor fiber is attached).

v8.5

- changed internal reference compensation calculation; now also two reference FBG supported
- TEK and OEK now saved in flash memory.
- Protocol changed: setting TEK/OEK by sending value/1000 instead of value/10000
- added: sectionwise defined TEK values (up to 10 supporting points) for onboard calculations possible
- now negative values for T_0 possible (-273.15°C...+327.0°C)

v8.6

- fixed: clipping of spectra (max. value: 51000) when using averaging > 1
- fixed: time constant very high when using averaging > 1
- protocol change in transferred peak / spectra arrays: offset*10000 instead of offset*1000

v 8.7

- code optimizations

v8.8

- added: setting TEK constant for every single fiber in multi-fiber-systems now possible

v8.9

- added: error code (fiber breakage / signal quality of each FBG channel) now calculated on board
- code optimizations

v9.0

- added: approximation of on board TEK value by cubic polynomial possible
- added: calibration ID can be saved in the device's flash memory

v9.1

- code optimizations

v9.2

- fixed (only applies to X1-devices): errors in `TeKPs>` command (cubic polynomial parameters)

v9.3

- added: onboard auto-optimize function
- fixed: corrupt spectra in UART mode 4 (used e.g. in multi-fiber-devices, since firmware v8.9)
- added: multiplex number can now be set and saved in flash memory for devices without physical ID pins
- optimized startup behaviour of internal temperature sensor's signal

v9.4

- fixed: commands `OBseT0/OBsWL0/OBsTK/OBsTyp` were ignored if respective channel number < overall channel number of first fiber
- optimized rounding of channel borders to nearest pixel
- added: new setting that defines if reference compensation shall be activated at device startup

v9.5

- replaced sectionwise TEK interpolation mode (mode 1) by global cubic polynomial TEK calculation
- global TEK interpolation parameters for up to four different fiber types can be stored in EEPROM

v9.6

- fixed: Auto-optimization algorithm sometimes did not converge for intense signals (i.e., X150), and answers contained invalid numbers for integration time / averages
- Auto-optimization further optimized
- signal quality error bits (e?> command) now also set at intense, clipping signals (intensity > 63000)
- in peak following mode, when error bit is set: channel borders now remain unaltered at their last valid position (before: reset them immediately to their original position like in "not-follow-peak case")

v9.7

- optimized: slight temperature errors occurring after zeroing if "TV" polynomial is not exactly the reverse function of the "VT" polynomial.

v9.8

- fixed: follow peak function sometimes ceased following when using narrow channels or small follow peak limits values (set by "PNg, x>" command)

v9.9

- general code optimizations
- fixed: KalID> command returned error code array instead of calibration number (only UART transmission affected)
- center of gravity peak detection mode: optimized accuracy if peaks are near the channel borders
- fixed: in center of gravity peak detection mode, peak amplitudes were slightly off since ver. 9.8. (peak position accuracy was not affected, though)
- fixed: with periodic darkframe update enabled and dark frame subtraction disabled, the darkframes were subtracted nonetheless (optimization of ADCC, x> and ADBA, x, y, z> commands)

v10.0

- fixed: since v9.3 devices do not set the ID pins correctly after saving EEPROM in stacked state
- increased internal measurement frequency from 220Hz to 300Hz
- saving streaming interface selection to EEPROM
- fixed: instabilities when channel borders nearing pixel number boundaries with "follow peak" active
- protocol changed: removed different UART transmission modes; instead now answers are sent to the interface that the respective command came from (USB or UART). Therefore:
 - UARTse, x> command obsolete
 - #UARTModus_999" instead of #UARTModus_1...4" in p?> command answer string
- fixed: in four-fiber port systems quickly setting many FBG channels at once resulted in corrupted channel borders
- general code optimizations

4.2 BraggSens changelog

v 1.60 (November 2019)

- channel width control (appearing when "insert" is activated) added
- "cfg" file format changed to "cfg2" (actual background spectrum and other information included)

v 1.61 (November 2019)

- Fixed some replay-mode issues

v 1.62 (January 2020)

- restore all settings (now .cfg3, including gaussian width information and the like)
- automatic Gaussian width update
- inserted "T": temperature compensation for FBG/Temp. FBG insert
- inserted: "zero strain"
- added support for FiSpec M120

1.64 (February 2020)

- Added Auto-optimize: program can try to get the best combination of integration time/averages to achieve a preset measurement frequency

v 1.65 (March 2020)

- global channel offset possible
- changed config file format to .cfg4 (added global channel offset)

v 1.66 (March 2020)

- added command line parameters

v 1.67 (April 2020)

- added raw peak wavelengths recording
- added subsequent "/recWL" command line parameter

v 1.7 (May 2020)

- optimized speed of Gauß peak detection; deleted simple peak detection
- added Auto-set channels
- Replay of Strain/Temperature possible

v 1.71 (June 2020)

- minor bugfixes
- supports new firmware 7.0: switch for onboard center-of-gravity peakdetection
- changed config file format to .cfg5 (peak detection method added)

v 1.72 (June 2020)

- optimized auto peak search for FiSpec X150
- added option to change x-axis of the strain/temperature graph (time/date instead of seconds x-axis). However, data file formats were not changed (time still in seconds).

v 1.80 (August 2020)

- supports new firmware 8.0: periodic darkframe update, new drift compensation

v 1.81 (August 2020)

- updated standard values for clear first software start and already enabled drift compensation

v 1.82

- non official version

v 1.83 (November 2020)

- supports firmware ver. 8.6 (new drift compensation methods)
- splitting long time recording data in several files (file size selectable)
- choose onboard strain/temperature compensation values for offboard calculations

v 1.85 (February 2021)

- changed auto optimize function (now: no threshold needed)
- for devices with onboard autostart setting enabled: light source is not being switched off after stopping measurement
- drift compensation of measured spectra now supports firmware versions 8.3 and newer

v 1.86 (March 2021)

- added ISO format timestamp for saved data

v 1.87 (March 2021)

- fixed: "auto-set channels" found no channels with certain devices
- added: "auto-set channels" threshold for extreme peak detection conditions (high noise / contrast)

v 1.88 (October 2021)

- "cfg5" file format changed to "cfg6" (UDP/darkframe/filesize/timestamp settings added)

v 1.89 (November 2021)

- devices with new Firmware versions (v 1.x) fully recognized
- different Baudrates possible when 5MBd-FTDI-chip detected
- added "disable Streaming mode at connection" option