FiSpec FBG Sensor Systems

FBG-Interrogator

Software Handbook

Software version covered in this handbook:

FiSens FBG-Interrogator 4.0

Contents

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
```
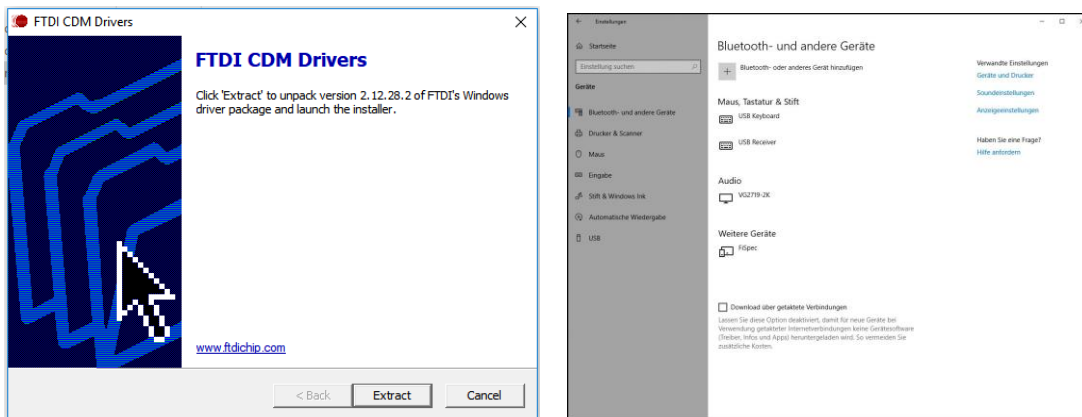

Fig. 1 FTDI driver installation window (left). Readily installed FiSpec in Windows Settings (right).

Further information can be found in the PDF files in the same directory. After successfull 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

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

```
[…]\FiSens FBG-Interrogator 2.0 Install\Volume\FiSens FBG-Interrogator Install.exe
```

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

During the installation, a shortcut to FBG-Interrogator will be placed on the desktop.
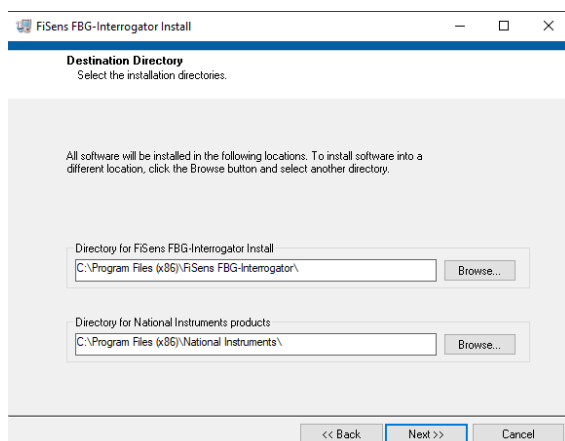
Fig. 2 LabView runtime environment installation.

1.2 File types and directory structure

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

\Users\[user name]\ Documents\FiSens\FBG Sensor Plane Configurations\Peak detection channels

This folder contains files with `*.channels` extension. These are binary files each comprising a complete set of "on board channels" array (for details, see chapter 2.3).

\Users\[user name]\ Documents\FiSens\Software Configuration files

In this directory, the FBG-Interrogator software saves certain settings it wants to remember for its next startup in the

`FBG Interrogator Program Settings.cfg`

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

\Users\[user name]\ Documents\FiSens\Saved Data

This folder contains the user saved data (for details, see chapter 4.2). 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 text files `(*.txt)` for strain, wavelength, intensity, and temperature data. Spectra are saved both in text files and graphics files `(*.PNG)` at the same time.

1.3 Connecting FiSpec devices

USB based spectrometers should be plugged into a USB port providing them with sufficient electrical current without the voltage dropping too much. So long cables, stacked unpowered USB hubs or the like may result in erratic behaviour.

In general, single devices with a single fiber port draw about 200mA current. Devices with four fiber ports or with SLED light source need more electrical current. Also take into account if there are additional devices like Ethernet converter boxes and beware that with WiFi adapters there will be current peaks due to communication bursts.

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 after a few minutes.

USB connected devices will show up in the device manager as serial port. 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. 3). 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.
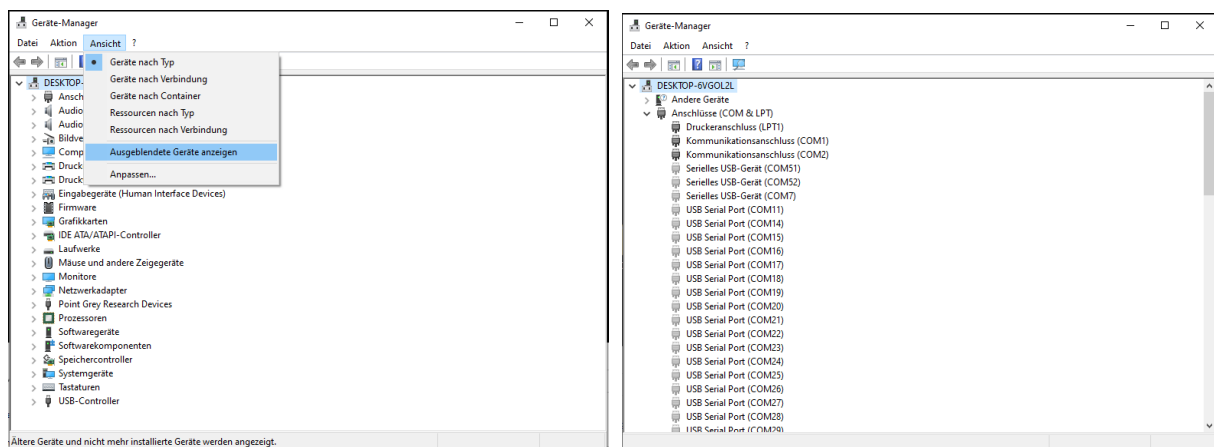
Fig. 3 Showing hidden devices in Windows device manager (left). Previously hidden COM-Ports (right).

2 The FBG-Interrogator software

2.1 General remarks

As opposed to the FiSens BraggSens program, the FBG-interrogator program supports all sorts of FiSpec devices, be it with single or multi fiber ports, stand alone or stacked, connected via USB, Ethernet, WiFi or serial (RS485, RS232, Bluetooth) connections. All of these can be connected and their measurement results will be shown at the same time. Beware, however, that with several devices connected, the measurement frequency of all devices will be the same, being limited by the slowest one of them all.

In general, when exiting the FBG interrogator software the program settings will be saved to disk (see chapter 1.2). So the main settings have to be done only once. Beware that, as opposed to the BraggSens program behavior, this does not apply to the FBG channel settings! BraggSens sets all FBG channels at program startup, whereas FBG-Interrogator uses the FBG channels that are already set up in the devices. So in case new channel settings are set while using FBG-Interrogator, these will be lost after the next power down unless they were saved to the respective device's EEPROM.

In general, when the mouse cursor crosses the program control elements and stays there for longer than a second, there will be some context help shown.

2.2 Setting up the program and starting measurements

Once you start the FBG-Interrogator program, the screen will look like shown in Fig. 4. No devices will be connected automatically.
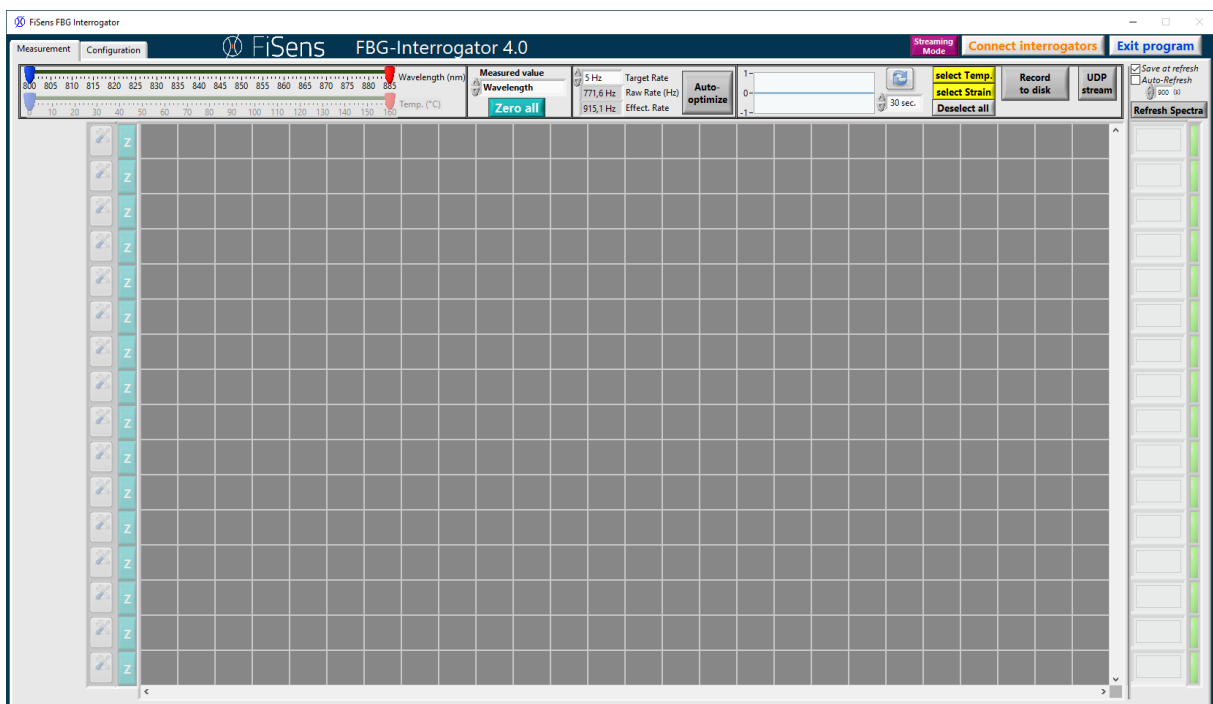
Fig. 4 Program interface after start-up.

This main front panel can be accessed by clicking the "Measurement" panel (see upper left corner). The following sub-chapters show how to do measurements. If your devices are not USB driven, however, firstly the device search options have to be set up depending on the interface used (USB, UART, …) like described in chapter 3.1. Other in-depth options hide in panel "Configuration" and are described in chapter 3.

To connect to the FiSpec devices and start measurements, click on the "Connect Interrogators" button. Depending on the connection type, the number of devices and the optimization target rate this process may take several seconds. If, however, the "Connect Interrogators" button turns to deactivated state again, no devices were found. In this case, check the device manager to see if there are any devices found or maybe the FTDI driver still has to be installed (see chapters 1.1 and 1.3).

If devices were successfully found and connected the program will look like shown in Fig. 5:
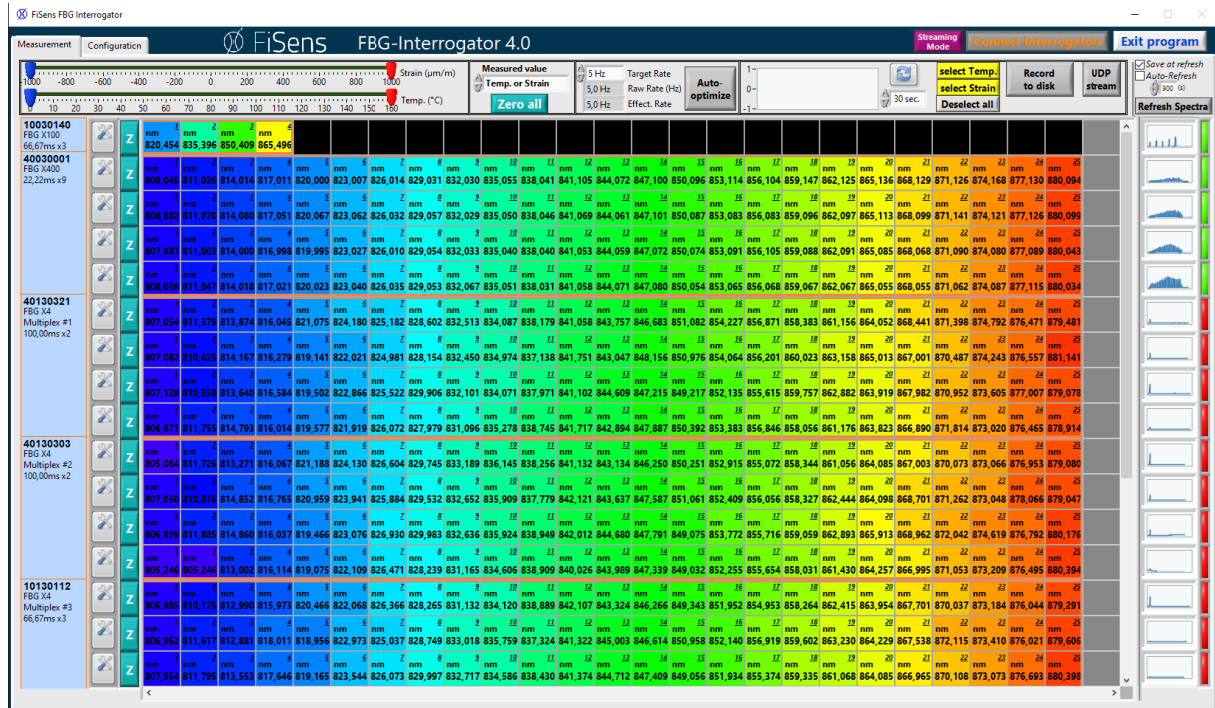
Fig. 5 FBG-Interrogator software front panel with different FiSpec devices connected.

Each sensor fiber connected to a fiber port is represented by a horizontal array of colored squares, with each square indicating the measured value of a single FBG sensor plane. A maximum of 32 FBGs in one sensor fiber is possible; the FBGs are numbered starting from "1" for every fiber (underlined number in the right upper corner of a square). The squares further contain the measured value (lower number) and unit (in Fig. 5, "nm", as wavelength values are chosen). Solid black squares (like in the first row in Fig. 5) do not indicate any FBG.

The borders between different devices are shown by orange lines. In Fig. 5, for example, there is a single fiber port X100, followed by a four-fiber-port X400. After that, a stack consisting of four-fiber-port X4 devices is connected, which can be recognized by the "Multiplex #x" in the information field on the left.

USB, Ethernet and UART connected devices are sorted in ascending serial number, followed by stacks (if any). Stacked devices, however, are strictly sorted by their physical stacking order regardless of their serial numbers.

The information field contains not only device name, serial and multiplex numbers, but also information about the actual illumination settings (for example, integration time 22.22ms and 9 averages: "22,22ms x9").

On the upper left side of the front panel there are two large sliders, whose designation changes according to the actual measuring mode. The results are coded with rainbow colors ranging from

blue to red according to the settings of the sliders (for widening or narrowing of the adjustment range, see chapter 3.3.2).

2.2.1 Setting the measurement frequency

To set a specific measurement frequency, choose the desired target rate in the Auto-optimization settings (see Fig. 6) and click the "Auto-optimize" button. After some time (up to a few seconds) the measurements continue with the new measurement rate. According to the measurement setup (light source, FBG reflectivity, …) the connected FiSpec devices may set different combinations of integration time and averages.
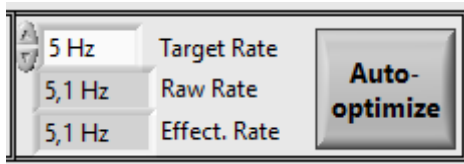
Fig. 6 Auto-optimization settings.

The algorithm tries to optimize the maximum signal amplitude while still regaining some headroom, and further optimizes the averages to reach the desired frequency to get the best signal quality possible. Optimization bases on the transfer rate of the USB connection and the number of channels to be transferred. The device estimates the interface limitations (FiSpec X100: about f_{max}=300Hz) and does not optimize for higher frequencies; in this way the optimal signal quality is derived.

So for low frequencies, the best integration time often is shorter than the frequency would suggest, and instead the averages are raised. If, for higher frequencies, the intensity is not high enough even when using no averaging (averages=1), the integration time is shortened according to the frequency nonetheless (for example, if 200Hz are set, the integration is a maximum of 1/(200Hz)=5ms).
For multi-port systems (for example, FiSpec X400), the intensity of the maximum intensity fiber port is being used for optimization to avoid overexposure.

"Raw Rate" (see Fig. 6) is the frequency the data is received by the computer. It should be near the set target rate. The "Effective Rate", however, is dependent on the calculation power of the computer and may be a bit lower depending on the amount of visualisation or recording activities.
Under certain circumstances, the measurement frequency is significantly less than desired and the buttons "USB latency" or "highspeed mode" appear on the front panel. in this case, refer to chapter 2.2.8 for details. In general, measurements over ethernet are significantly slower than with USB based devices.

2.2.2 Choosing the measured and shown value unit

Fig. 7 Dropdown menu for „Measured value" (left). Sensor fiber containing both strain and temperature FBGs (right).

The onboard peak detection of FBG spectra firstly results in peak wavelengths and intensities. Furthermore, in principle, every FBG inside an optical fiber can be used as a temperature or strain sensor, depending on the way it is mounted. The actual use of each FBG is defined in the channel

settings (see chapter 2.3), so that the changes in the peak wavelengths relative to the zero wavelength can automatically be converted in either strain or temperature values.

The FBG-Interrogator software therefore shows either the calculated values (temperature or strain, depending on the respective definition), wavelengths or intensities. This can be chosen by the dropdown menu shown in Fig. 7 (left).

Fig. 7 (right) shows an example for the „Temp. or Strain" case: almost all FBGs are defined as temperature sensors. Fiber port 2, however, contains three strain FBGs, with a therefore different unit (m/m instead of °C). In Fig. 5, on the contrary, wavelengths are shown. Here the FBG definition makes no difference, as wavelengths are measured for all FBGs anyway; all measurement results are shown in the unit „nm".

Recording, graphical visualisation and UDP streaming always use the value unit chosen at that time; therefore it is not advisable to change the setting during recording or streaming.

2.2.3   Miniature spectra and signal level indicators

After connecting the devices and after each Auto-optimization spectra of all connected devices are measured automatically once and shown in the miniature spectra column (see Fig. 8, left). The y-axes are not auto-scaled; in this way it is possible to determine at one glance how well the current integration time and sensor reflectivity match, and if there is some possible problem. For a detailed view, left-clicking on one of the miniature spectra will show this spectrum in a separate window (see Fig. 8, right). The y-axis in this window is auto-scaled. At the bottom of the spectrum, the actual shown fiber port and device name is written. By clicking on the green up and down arrows as well as using the PgUp/PgDwn buttons it is possible to scroll through all fiber ports.

Next to the miniature spectra, green/red lamps are shown. These are signal level indicators reflecting the microcontroller's decision of whether the signal/noise ratio is good enough or not. If red, the signal of at least one of the peak detection channels at this fiber port is decided to be faulty. This could for example indicate a broken fiber. If this is not the case, a red light does not necessarily mean that the measured results are unuseable; they could just be more noisy than usual and it might be considered to increase the integration time, however.
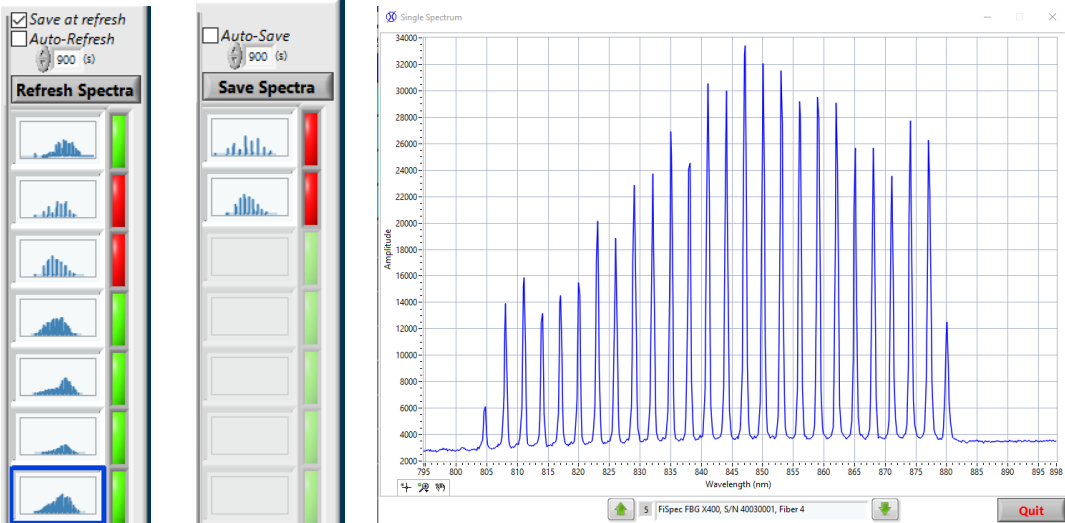

Fig. 8 Miniature spectrum controls and signal level indicators (left). Changed layout in blockwise streaming mode (middle). Single spectrum window (right).

Firmware versions from v10.4 offer additional error code information: While clicking on one of the green or red signal level indicators, a window like shown in Fig. 9 (left) appears. There are four different error codes; as soon as a certain error occurs for at least one of the peak detection channels of this fiber port, the according lamp will be active.
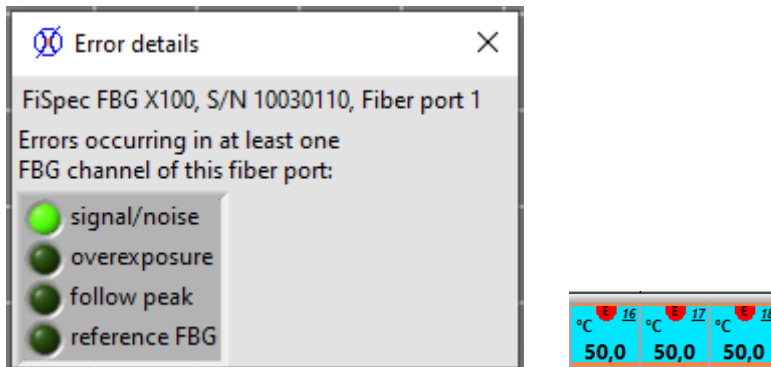

Fig. 9 Error code window for a single fiber port (left).   Individual peak detector channel error indicators (right).

Furthermore, errors are shown individually by "red dots" in the respective data box (see Fig. 9, right).

The spectra can be refreshed manually ("Refresh Spectra" button, see Fig. 8, left) or automatically at a given frequency, if desired. If the "Auto-refresh" option is activated, the miniature spectra are automatically updated at a adjustable time interval. In Fig. 8, for example, this interval is set to 900s.

If the "save at refresh" option is activated, all spectra will also be saved to disk after every automated or manual updating. This is especially useful if one wants to monitor the measured spectra over time (for example, to check if peak intensities drop). Beware, though, that measuring the spectra causes a certain delay; so for high frequency measurements this option should be switched off if low timing jitter is of concern.

Keep in mind that when operating in blockwise streaming mode (see chapters 3.2.6…3.2.9), the layout of the refresh/save spectrum buttons is a bit different (Fig. 8, middle). In this mode, the spectra are refreshed automatically (if activated so in the settings, see chapter 3.2.7) and saving them to disk can be done automatically or manually at any time.

Furthermore, also the signal level indicators can be repeatedly updated automatically (see chapter 3.2.1). Beware that the miniature spectra and signal level indicators do not necessary reflect the actual state of the measured signals! They only show the system's state at the time the spectra/indicators were updates last time, be it automatically or manually.

Additionally, there is an option "Save spectra at refresh" (Fig. 8, left). If activated, after refreshing the spectra are saved to disk both as a `*.png` graph and as a text file. The filename consists of device serial number, Date, time, and fiber port number (for example, "`10020179_2022-03-28_11-29-07_0.txt`"). This option can also be used together with the beforementioned automatic spectra refresh to monitor the measured signals. The first line in the text file consists of integration time (in milliseconds) and averages.

2.2.4 Zeroing of sensors
For high accuracy measurements every combination of a sensor fiber and a device fiber port needs to be zeroed at least once before measurements, i.e. the exact zero wavelength has to be determined.

To do so, the fiber is being exposed to the pre-defined zero temperature T_0 and has to be mounted in the final measuring position (which may induce a certain unknown pretensioning). Then, the actual wavelength is measured and saved. This process is called "zeroing".

For practical reasons, there are two possible ways: if all connected fibers at all devices are at their respective zero temperature, zeroing can be accomplished by just pressing the global "Zero all" button (see Fig. 10, left). If, however, only certain fibers were exchanged, it is possible to measure only the specific zero wavelengths belonging to that fiber ports ("Z" button; see Fig. 10, right).
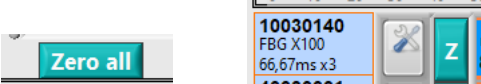
Fig. 10 Global zeroing (left) and single Fiber port zero and settings (crossed tools) buttons (right).

It is also possible to set the zero temperatures of all connected fibers at once before zeroing. For details, see chapter 3.2.4.

To calibrate a certain combination of sensor and FiSpec device (single-point calibration), the actual temperature at the sensor fiber has to measured with a thermometer and the zero temperature T_0 has to be set accordingly. After that, zeroing has to be done. If the current state is then saved to the spectrometer's flash memory, the calibration of the combined system of sensor and interrogator will remain even after cycling the power.

2.2.5   Selecting sensors

After connecting the interrogators, the measurement result of every connected FBG sensor is shown as one of the colored squares arranged on the front panel. The user now has to decide which sensors's data shall be graphically shown, recorded or streamed from now on. Selected sensors show a yellow background behind the sensor number.

To determine the sensors of interest, there are a few methods (buttons shown in Fig. 12):

- select all temperature sensors: left click the "select Temp." button
- select all strain sensors: left click the "select Strain" button
- select single sensors: right click on sensor
- select rows or rectangular patterns: right clicking a sensor while holding the CTRL key will select all sensors in a rectangle whose corners are defined by the now clicked sensor and the sensor that has lastly been selected before. An example is shown in Fig. 11. This function can also be used to select all FBGs of a single fiber ports by "right clicking" the first sensor and "CTRL+right clicking" the last sensor.

Fig. 11 Selecting a rectangular pattern: select FBG Nr. 8 (lower row) by right click (left picture). Then select FBG Nr. 10 (upper row) by CTRL+right click (right picture).

To deselect sensors, use the following methods:

- deselecting all sensors: left click "Deselect all" button
- deselecting single sensors: right click the already selected sensor.

2.2.6 Data visualisation
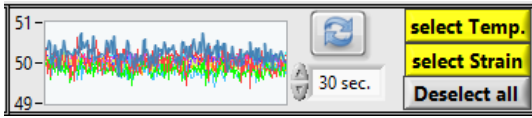
Fig. 12 Visualisation panel. Left: Graphical visualisation. Middle: Refresh button (up) and time span setting (down). Right: select and deselect buttons.

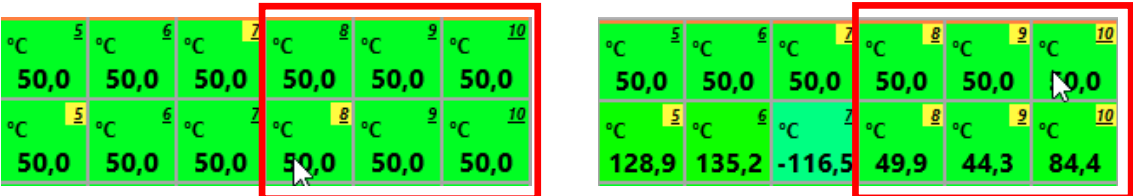Once sensors are selected, their measured data is shown in the miniature graph (see Fig. 12). The time span of the x-axis is selectable. Beware that for high measurement frequencies and long time spans the amount of data to be shown may be quite overwhelming to the computer and the overall program may be slowed down. This will result in a dropping effective Rate (see Fig. 6).

When left clicking on the small visualisation graph, a freely movable window with a bigger graph appears (see Fig. 13). The "Visualisation Span", "Zero all" and "Reset graph" buttons are duplicates of the ones on the program's frontpanel. Furthermore, there is a Pause button (shortcut button F9); the graph will stop updating as long as it is pressed, while the processes in the main program are still continuing (e.g., measurements, recording, UDP transmission).
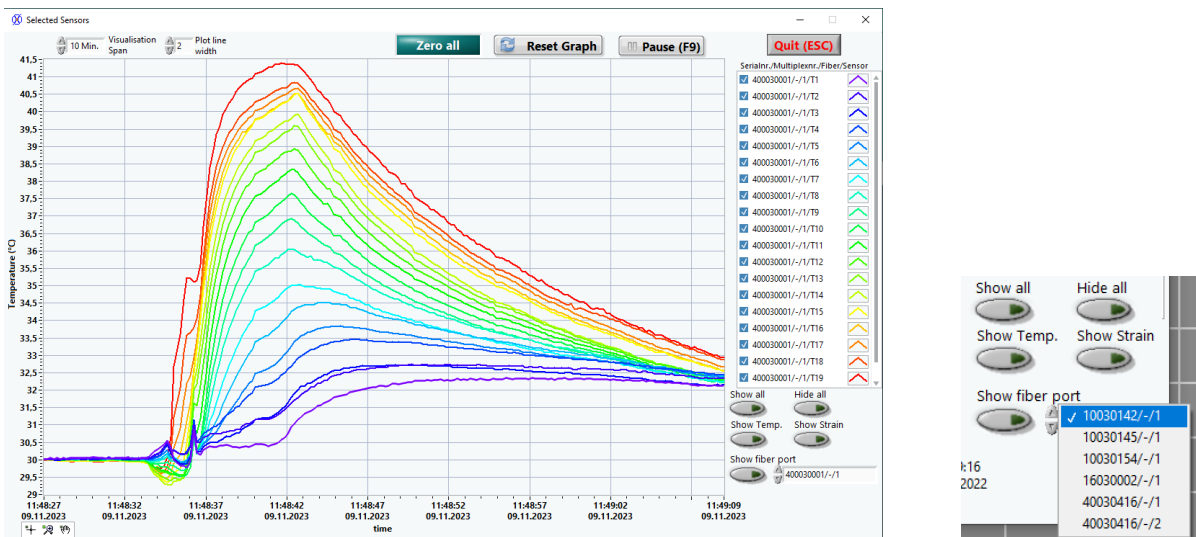
Fig. 13 Visualisation window (left). Sensor visualisation tools with fiber port drop down menu (right).

If the tick mark in front of the sensor number in the legend list is selected, the matching data is shown in the graph. This tick boxes can be activated and deactivated manually; they are purely for visualisation purposes and do not affect recording or streaming. In the lower right corner there are some additional tools that help sorting the shown graphs: "show all" and "hide all", as well as "show Temp.", "show Strain" and "show fiber port". The latter can be used for adding all sensors of a specific fiber port that can be specified in the drop down menu (see Fig. 13, right). If, for example, you want to only see the sensors of fiber port 10030142/-/1, first click "Hide all", choose "10030142/-/1" and click "Show fiber port".

Furthermore, there is another way to show the graph of only one specific FBG sensor. By left-clicking this sensor in the front panel, the visualisation window shows up with all graphs except of the chosen one deactivated. This only works if this specific sensor has been selected before.

2.2.7 Changing fiber port (i.e. FBG channel) settings

It is possible to change the FBG channel settings of every fiber port by clicking the crossed tools symbol on the left side of the front panel (see Fig. 14). Also saving settings to the EEPROM of a specific device and communication via a basic terminal functionality are possible.
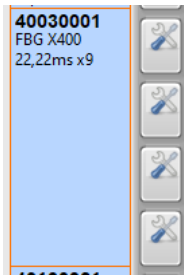
Fig. 14 Fiber port settings buttons.

The main window will be hidden while the settings window is open. Beware that measurements as well as recording data to disk and UDP streaming are globally paused during settings window!

Chapter 2.3 describes in detail how to use the Settings window and change the FBG channel settings.

2.2.8 Buttons "Optimize USB Latency"

The optimization of the USB port latency plays an important role in obtaining high measurement rates. The microcontroller on board of the FiSpec device sends the latest spectrum or peak information immediately after receiving the corresponding command. 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, is 16 Milliseconds. So the maximum frequency achievable is about only 60 Hz. By changing this value to 1ms, the maximum frequency can be greatly enhanced. This can be done manually by the user in the device manager. However, the FBG Interrogator software is able to change the Windows Registry on its own if started with Administrator privileges (right-click on the FBG-Interrogator icon and choose "run as administrator"):

If the FBG-Interrogator software detects at least one device connected via USB whose latency is not set optimally, the maximum measurement frequency will be below 60Hz and the button "Optimize USB Latency" is visible on the upper right side of the frontpanel (see Fig. 5 and Fig. 15):

Fig. 15 USB latency and streaming mode buttons.

After clicking on "optimize USB latency", a window appears that asks for confirmation (see Fig. 16).
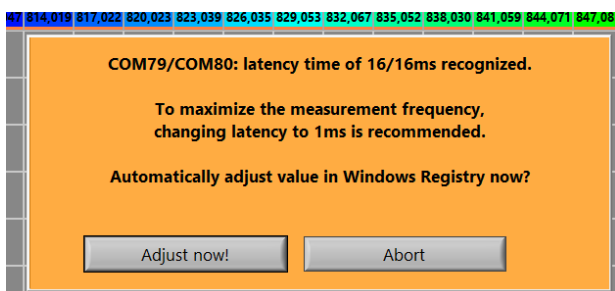
Fig. 16 Confirmation window for latency time changes.

After confirming by clicking "Adjust now!", the windows registry is permanently updated. The connection to the devices has to be stopped and started again by clicking „Connect Interrogators" two times. Now it will be possible to achieve higher measurement frequencies well over 60Hz.

2.2.9 "Streaming Mode" button

In polling mode (computer continuously asks the FiSpec device for new measurement results and waits for the answer) the USB overhead and latency time plays an important role in restricting the measurement frequency, especially for high measurement frequencies. Thus, the FiSpec devices are able to continuously send one result after the other in streaming mode, with the computer just passively listening to the stream without the necessity to send further commands.

The streaming mode implemented in the standard FiSpec devices (X100, X400, …) sends the data in the same format it transmits data in polling mode (peak wavelengths/ intensities/ strain/ temperature). So to gain additional information about the current state of the device (error codes, spectra, signal levels), the stream has to be interrupted, the desired information gained by other commands, and afterwards the stream has to be started again. So this, along with the USB latency issue, also causes significant delays, jitter, and dropped frames, which naturally in high speed measurements are undesirable. So our high speed devices (to date this is the FiSpec X1000) support, besides of the "old" streaming protocol, a new blockwise streaming protocol (up to 64 measurements in one block). This protocol always contains the error code/signal level information, as well as (if desired so) complete spectra. Further information can be found in chapters 3.2.6…3.2.9.

If only "slow" devices (or a mixture of slow and blockwise-streaming spectrometers) are connected, the "Streaming Mode" button is colored in purple. However, as soon as every connected device supports the blockwise streaming mode, the button turns yellow to indicate that (see Fig. 17).

Fig. 17 Streaming mode buttons. Left: only normal streaming mode available. Right: all connected devices support blockwise streaming mode.

After activating the streaming mode button, the refresh rate of the front panel and graphs may slow down, according to the settings, in the blockwise streaming mode, as described in chapter 3.2.6.

2.2.10 Buttons „Record to disk" and „UDP stream"

Once at least one sensor has been selected (for details, see chapter 2.2.5), the measured data can not only be visualised, but also recorded or UDP streamed. By activating the "Record to disk" button (see Fig. 18), the corresponding data is saved to files; same is for the "UDP stream" button.

Fig. 18 Activated "Record to disk" button with actual file size ("375kB") and actual file number ("3"). Activated "UDP stream" button with actual streaming frequency ("246.1Hz").

Beware that only data of selected sensor planes will be saved or streamed! It is possible to restrict the file size and change timestamp format and decimal point (see chapter 3.3.1). Details about the text file format are described in chapter 4.2, and the UDP format is described in chapter 4.1.

2.3 The "Interrogator Settings" window

2.3.1 Changing fiber models, device settings and peak detection channels

By clicking the crossed tools button (see Fig. 10, right) next to a specific fiber port's sensor row in the front panel, the measurements will pause, the front panel will disappear and an "Interrogator settings" window will show up (see Fig. 19). In this window, the peak detection channel settings of a single device can be changed. If the device offers more than one fiber port, it is possible to switch through the fiber ports by using the PgUp/PgDwn key.
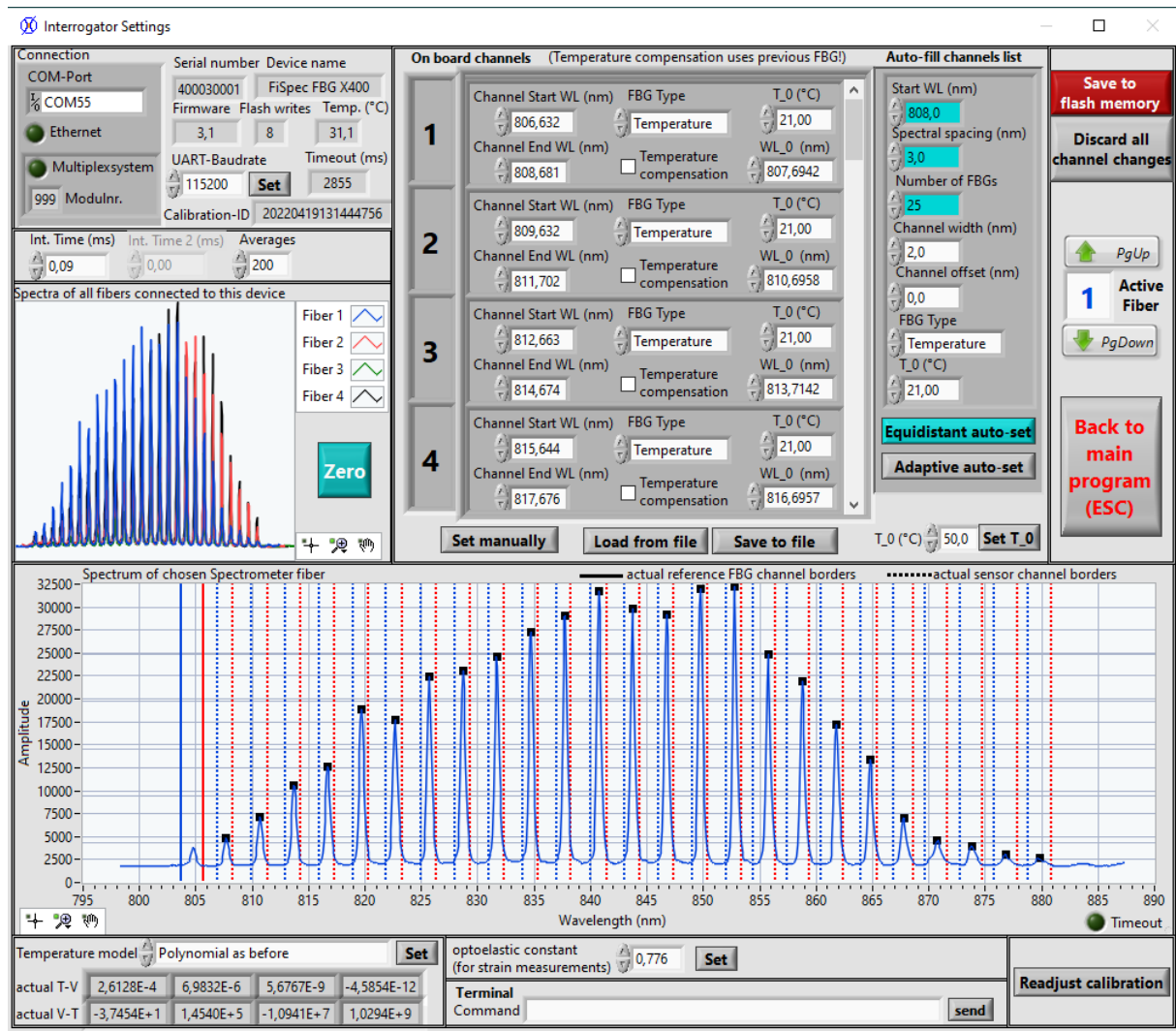
Fig. 19 Interrogator settings window.

On the bottom, a rudimentary communication terminal is located. For experimental purposes, commands can be sent to the device according to the programmer's manual. Furthermore, on the bottom left side the temperature model polynomial coefficients that are set for this fiber port are shown. If the set of coefficients is identical to one already defined in the "temperature model builder" (Configuration=>Temperature model builder, see chapter 3.4), the name of said parameter set is shown here; else "Polynomial as before" is shown. Any one of the predefined temperature models can be chosen here; in multi fiber port devices it is possible to have different polynomials in each fiber port.

On the middle left, all spectra of the device are shown in real-time, i.e. if the device offers four fiber ports, all spectra are shown at the same time in different colors. This enables one to view and

compare all intensities at one glance. The big graph at the bottom shows the spectrum at the active fiber port, the active peak detection channel borders (broken lines; left border: blue, right border: red), the reference FBG detection channel borders (solid lines), and the detected peak positions (black dots).

In the upper middle, a list of the onboard peak detection channels is shown. This list shows the values read directly out of the device, so the border wavelengths might slightly deviate from the desired wavelengths according to the physical pixel wavelengths.

To manually add or delete a single FBG channel, right-click on the array and choose "insert element before" or "delete element".

The peak detection channel ranges from "Channel start WL" to "Channel End WL" (WL=wavelength). It can be chosen to be a temperature or strain FBG. The zero wavelength and zero temperature can also be set here.

By definition, if an FBG is used as a temperature compensated strain FBG ("Temperature compensation" activated in the list), the temperature measured by the FBG located in the peak detection channel directly above in the list is used as the corresponding compensation temperature.

As soon as the channels list is different to the presently active settings in the device, the related list entry and the "set manually" button are marked in yellow (see Fig. 20). Clicking the "Set manually" button then transmits the channel list to the device. After that the device settings are automatically read out and the "onboard channels" list is updated. Like mentioned above, pixellation can cause the listed wavelengths to slightly differ from the desired wavelength values.
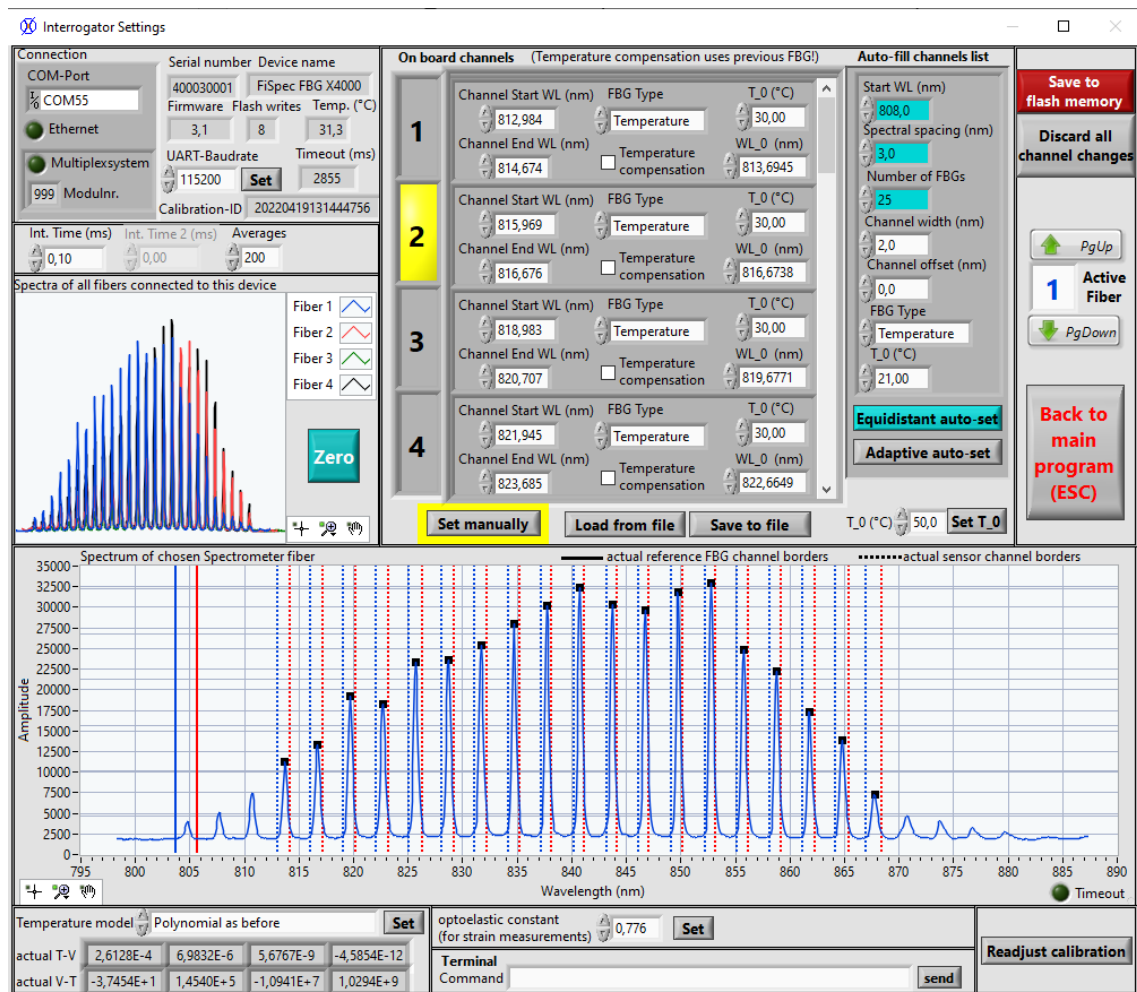
Fig. 20 Interrogator settings window: discrepancy between active device settings and entries in the "On board channels" list.

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It is also possible to automatically fill up the onboard channels list. In this case, the white numbers in the "Auto-fill channels list" sections are used:

- channel width: this value should be chosen depending on the free space between the FBG peaks. If the algorithm detects overlapping, it narrows the channels automatically, depending on peak width and peak distance.
- Channel offset: in general, this can be left "0". If, however, it is obvious that the values can only change in one direction (i.e., for strain FBGs that are zeroed in stress-free state, the wavelengths can only increase), it is possible to providently move both channel borders to higher wavelengths by adding a channel offset, whereas the zero wavelength remains untouched.
- FBG type: automatics only allows to set the FBG type to either temperature or strain.
- T_0: automatics only allows to set the same zero temperature to all set channels.

There are two ways to auto-fill the on board channels list; both use the settings described above:

- Equidistant auto-set: this function uses both white and green numbers to create a set of "number of FBG", equally spaced peak detection channels, starting at "Start WL", with the zero wavelengths being "spectral spacing" nanometers apart.
- "Adaptive auto-set": this function tries to recognize FBG peaks and creates peak detection channels around them, using only the white numbers described above. As soon as the Adaptive auto-set button is activated, a threshold slider and Abort/Resume buttons appear (see Fig. 21): It is now possible to increase or decrease sensitivity by manually changing the "Auto-set threshold". Too low threshold results in supernumerous peak detection channels (Fig. 21, upper graph), while with a too high threshold not all of the peaks are being detected (Fig. 21, lower graph). Pressing the „Resume" button then transfers the found channels to the device.

Fig. 21 Optimizing the Auto-set threshold button: Too low=>too many channels. Too high=>not all peaks found.

Both automatic functions empty the "on board channels" list, replace it by their own guesses and send the new values to the microcontroller. If one wants to re-establish the settings that were active when entering the "Interrogator settings" window, the "Discard all changes" button at the right side can be clicked.

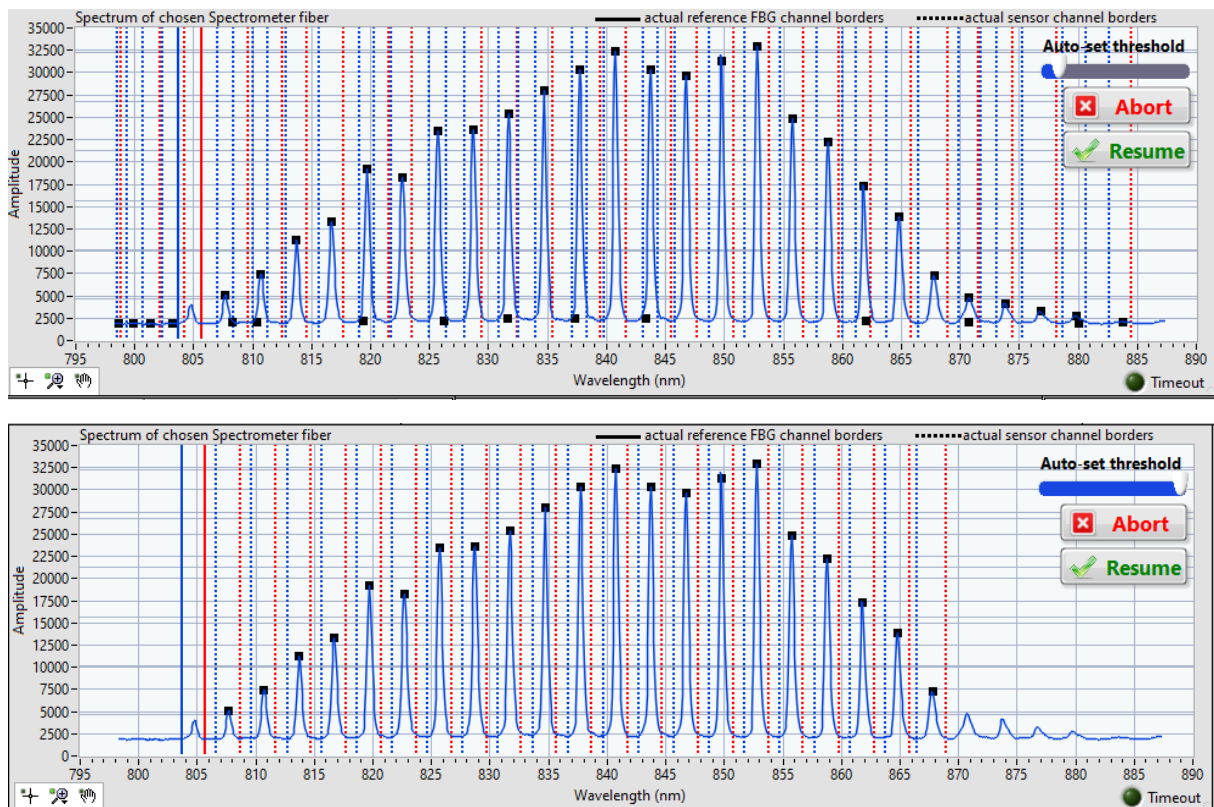Complete peak detection channel lists can also be saved to file or loaded from file by using the likewise named buttons. In this case, binary files are used that are specific to the FBG interrogator program. These files can also be used for setting up FBG detection channels in all connected devices at once (see chapter 3.2.5).

In case the new settings are satisfactory and should remain even after repowering the device, they can be saved to the device's non-volatile memory. This can be done by clicking the red "Save to flash memory" button. Beware that the warnings from chapter 3.2.11 apply; the saving function should not be used too often to avoid permanent corruption of the flash memory.

The "Settings" window can be left by pressing the "ESC" key or be clicking on the "Back to main program" button.

2.3.2   Readjusting device calibration in the settings window

Due to wear or ageing (heat cycles, mechanical shocks, vibrations) the interrogator's calibration may be off a bit after some use. In principle, this is not a problem if the "Use reference FBG" option is activated, as then all channel borders and peak positions are compensated. However, if the calibration is displaced in a way that the initial peak detection of the reference FBG itself is impaired, the reference compensation is not effective anymore and the device has to be recalibrated.

Instead of doing a full scale calibration at the factory, it might be sufficient to just adjust the offset of the internal pixel->wavelength calibration function. The FBG interrogator software offers such an automated functionality:

First adjust integration time and averages to ensure a good signal quality. Then, after clicking the "readjust calibration" button (see Fig. 20, on the right bottom), the expected reference FBG wavelength for the present device temperature is calculated out of the pair of calibration temperature and wavelength values stored in the device's memory. This expected value is compared to the actual measured wavelength. The difference can now be added to the offset of the internal pixel->wavelength calibration function by clicking the « Shift calibration now!" button in the popped up window (see Fig. 22).

Until then, no harm is done, as the changes are not yet saved to the device's nonvolatile memory. You can now double check if the wavelength is correct even without Reference FBG compensation by disabling "Use reference FBG" in the main program "Configuration->Device settings" panel and returning to the settings window. The reference FBG should now appear at 805nm (exact value depending on temperature and physical characteristics of the reference FBG).

To permanently keep this adjustments, press the "Save to flash memory" button on the upper right corner. Beware: this will permanently overwrite the offset value of your device's factory calibration function! The device's calibration-ID will be changed as well.

Actual reference FBG wavelength:
805.062nm.
Expected reference FBG wavelength at the present temperature:
805.063nm.
Want to shift the current calibration function by 0.001nm?

Shift calibration now!   Abort
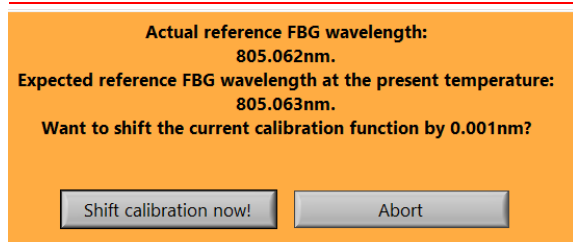
Fig. 22 Pop up window during calibration readjustment.

3 Configuration of program and device settings

In this chapter, the various settings available in the „Configuration" panel are described.

3.1 Panel „Startup=>Startup/connect settings"

To set up the device search, go to the sub-panels "Configuration" => "Startup/connect settings" (see Fig. 23). According to your devices' data interfaces the settings differ; different options may be chosen at the same time in case differently connected devices are used.

- Devices separately connected via USB
  - Choose for normal USB connected devices (FBG X100 or the like)
- Multiplexed/stacked devices via USB-connected interface boxes
  - Tick this box if your devices are multiplexed by a transparent hub (also internally), which is connected via USB. Beware: this setting does not apply to device stacks with Ethernet boxes; the USB connector there is only to set Ethernet settings and for power supply
- Devices via Ethernet/WiFi interface (single or stacked)
  - Tick this box if you connected ethernet or Wifi systems, be it devices with extension modules connected to the external UART connector or Ethernet convertor boxes for stacked devices. The IP addresses of all devices have to be set further down (blue "IP address" arrays).
- Devices connected to COM-ports (i.e. UART, RS485, Bluetooth)
  - If your devices are connected by a virtual COM-port, like RS232 or RS485 converters or by a Bluetooth connection, choose this option. In this case, the COM-ports have to be known and along with their respective baudrates added in the green array further down ("COM-port settings of UART/RS485/Bluetooth-devices").

If you want to delete any entrys in the blue or green arrays, right-click on it and choose "delete element".
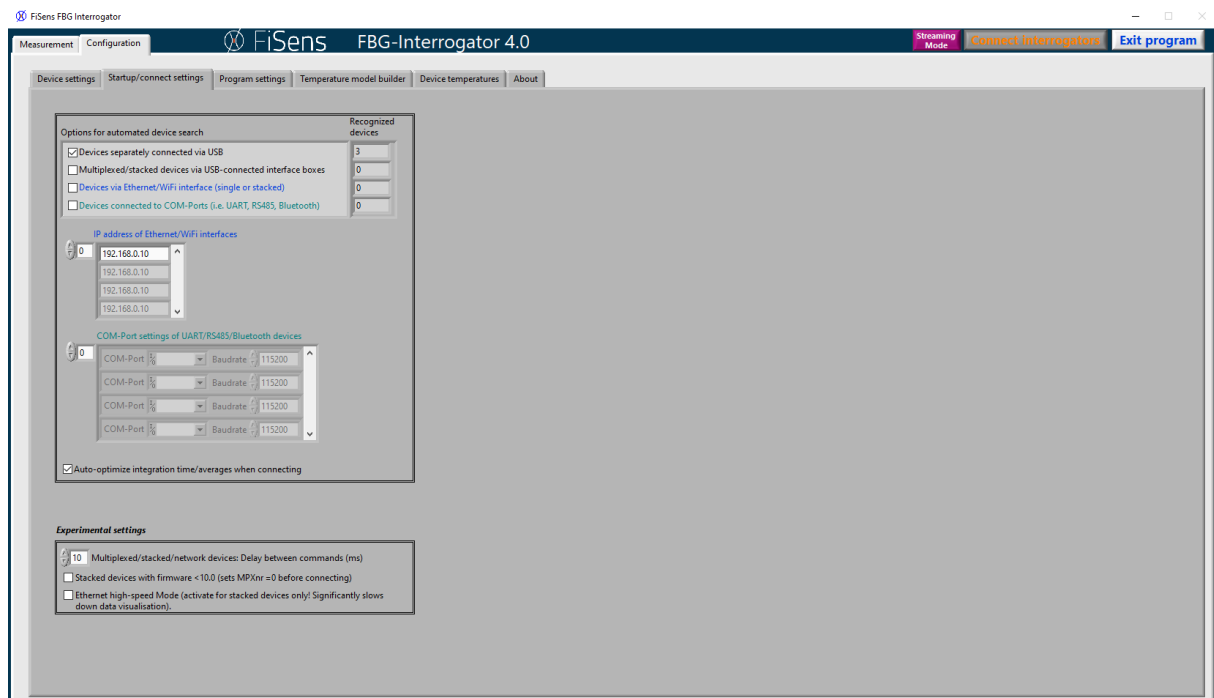
Fig. 23 Panel "Configuration=>Startup/connect settings".

Three other options allow for further customisation:

Disable streaming mode at connection (standard value: switched off): if streaming mode is activated in the flash memory of a device, it will flood the data interface. So in this special case, this option can be used to switch off streaming mode when connecting.

Auto-optimize integration time/averages at connection (standard value: switched on): usually after connecting an auto-optimization of all devices is carried out according to the setting in the front panel. If this is not desired and the devices should further continue with their settings already active, this option can be disabled.

Experimental settings:
For network connections with high delays it might help to increase the "delay between commands" value to solve communication problems.
Furthermore, with some computers the ethernet communication speed is affected by the front panel update rate; due to limitations of the LabView GUI, the measurement frequency drops slightly when using Ethernet connection while updating the frontpanel at the same time. So in case of seemingly slowed down stacked devices, it might help to activate the "Ethernet high speed mode" tick box. Beware that then the graphs and color squares on the front panel will no longer visibly change. However, under the hood everything still works like intended, so measurements continue, UDP data is sent and data is being recorded. As soon as the tick box is deactivated, the frontpanel will return to its normal behaviour and the graph will also show the data of the immediate past according to the settings.

3.2 Panel "Configuration=>Device settings"
In the sub-panel "configuration=>device settings" (see Fig. 24) it is possible to to define several measurement parameters.

Fig. 24 Panel "Configuration=>Device settings".

3.2.1 Automatically update signal level indicators in polling mode

The spectrometer internally evaluates the signal quality (signal/noise ratio) for each FBG channel continuously. If this tick box is activated, for example every 3 seconds the FBG-interrogator program will send the "`e?>`" command (see programmer's manual) to all connected devices and evaluates the answer. If at least one of the FBG channel signal qualitie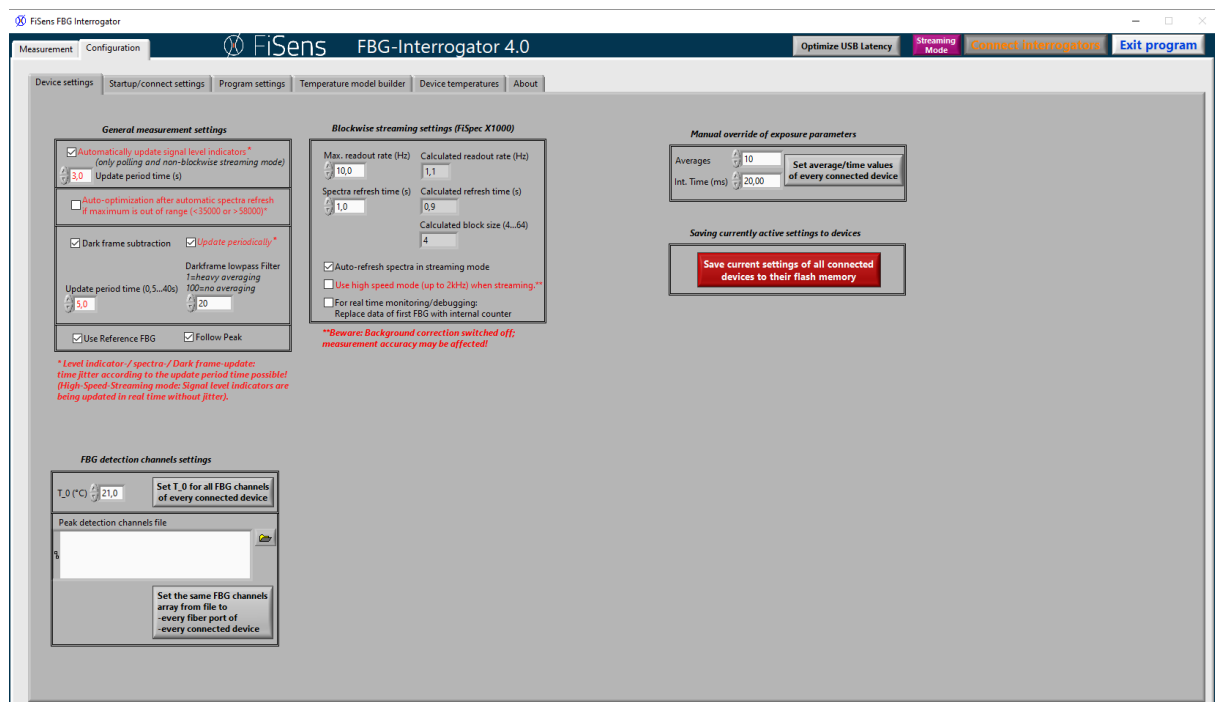s of a fiber port is reported as bad, the respective signal level indicator on the front panel turns red. This function is purely for informational purposes to quickly show problems like broken fibers, fiber connector problems or the like. Beware that the indicator showing up red does not necessarily mean that the measurement results are unusable (maybe they are just noisier than usual), but it is a good idea to have a closer look to make sure everything is okay and the measurements are still trustworthy.

Beware: as the additional command takes a bit of time to be processed, this option may cause timing jitter (especially with high measurement frequencies). So for measurements where evenly distributed measurements are important, this option should be switched off. Furthermore, this switch only sets the behaviour in the "normal" polling and streaming mode, which is used by all FiSpec devices. The new FiSpec X1000, however, supports the new blockwise streaming mode, whose protocol also includes error bits and occasional spectra (see chapters 3.2.6…3.2.8). So if all connected devices support blockwise streaming (indicated by the "streaming mode" button turning orange), this mode is automatically selected when streaming is enabled and the signal levels indicators and error signs will appear in real time without causing further jitter.

3.2.2 Auto-optimization after automatic spectra refresh

When operating the FiSpec under extreme conditions (for example, great ambient temperature changes), the light source intensities may vary, with signal intensities changing accordingly. To assure reliable results, this option offers automatic tracking based on the automatically obtained spectra: When activating this option, the FBG-Interrogator application checks if the maximum of each spectrum is neither too high (intensity >58,000 => danger of clipping) nor too low (intensity <35,000 => bad signal/noise ratio) after each automatic spectra measurement. If the maximum intensity of at least one fiber port is outside of this range, an auto-optimization of all devices is initiated.

Beware: if

- there is at least one fiber disconnected, or
- if the reflectivities of the sensor fibers connected to a multi-port device are quite different, or
- if the signal can't match the "optimum" window at all because of too high measurement frequencies ,

at the next auto-spectra-measurement time this condition is again met, and thus it might happen that the auto-optimization is taking place every single time spectra are updated.

3.2.3 Dark frame subtraction

The FiSpec devices offer sophisticated onboard dark frame subtraction which can be configured here. In principle, during factory calibration a 5 second dark frame is measured, which (scaled according to the actual integration time) can be subtracted from the measured signal before further peak detection operations. There are two selectable modes (for further details, see programmer's manual):

- "Adaptive dark current compensation" (ADCC), that uses the factory measured dark frame, and
- ADCC with activated "automatic periodic dark frame update" function, which uses the actual dark frame signal periodically measured during the measurements.

To use dark frame compensation *under normal conditions*, simply <u>activate "dark frame subtracting"</u> <u>and deactivate "update periodically"</u>. This function does not induce any further delays, works in most cases and reliably eliminates most of dark noise at typical integration times and room temperature.

However, at *higher ambient temperatures*, thermal noise of the detector gets more dominant and might impact the quality of the measurement results. For this scenario, FiSpec devices offer "automatic periodic dark frame update" mode, as they are able to automatically switch off the internal light source for single integration times. This function is used by <u>activating both "dark frame</u> <u>subtracting" and "update periodically"</u>. During this dark frame measurements, which take place every "update period time", the normal FBG sensor measurements will be delayed by about 1…2 integration times (no commands will be lost). So this automatic periodic dark frame update may not be used when such delays are not acceptable.

Naturally, single frames taken with the same integration time are noisier than the 5 seconds dark factory frame and lower the signal quality if subtracted. To overcome this issue, the successive dark frames can be smoothened by low pass filtering in time: each newly measured spectral intensity I_{df_new} adds to the previous dark frame intensity I_{df} weigthened by a factor W_{LP}:

$$I_{df}=[I_{df}*(100-W_{LP})+I_{df\_actual}*W_{LP}]/100.$$

So a darkframe lowpass filter value of "1" results in heavy averaging and lowest noise, but does not react as quickly to background changes. In opposite, a value of 100 equals to no filtering at all; therefore the background subtraction results in more noisy results, but immediately follows changes.

3.2.4   Set T_0 for all channels

In order to calculate correct temperature values, the device has to know the actual temperature of the FBG sensors while zeroing. If every single connected sensor is at the same known temperature T_0, here it is possible to set T_0 to the same number by clicking the "Set T_0 for all FBG channels of every connected device" button. After doing so, pressing the the "zero all" button at the front panel will result in all temperatures initially showing the same measured temperature value.

3.2.5   Peak detection channels from file

If there are the same fiber sensors connected to all fiber ports, pre-defined channel settings (saved in the "Settings" window; see chapter 2.3) may be set for all ports at once. The channel definition file (extension "`*.channels`") can be chosen from the hard drive and afterwards set to all devices by pressing the "set the same FBG channels…" button.

Beware, though, that different sensor fibers may have slightly different zero wavelengths. So immediately after setting channels in such a global manner the shown temperature values may be quite off, and it will be needed to set the respective zero wavelengths anew, for example by pressing the "zero all" button on the front panel, or by zeroing the fiber ports one by one.

3.2.6   Blockwise streaming mode: Max. readout rate/Spectra refresh time

For high speed measurements that don't have to fulfill real time requirements, the blockwise streaming mode is ideal. In blockwise streaming mode, several (="block size") measurements are transmitted in one large data chunk. The block size depends on the desired readout rate, which is the frequency in which the graphs are updated and data is sent via UDP. This frequency can be set here

and should not be too high to not overwhelm the capacities of the computer. The according block size and technically possible readout rate is then calculated automatically. For example, 10Hz is a good freadout rate that allows for halfway fluent data visualization.

3.2.7 Auto-refresh spectra in (blockwise) streaming mode

In normal polling mode the spectra auto-refresh function leads to significant delay/jitter in the measured data (see chapter 2.2.3). When using the blockwise streaming protocol, however, this is nearly insignificant. Every transmitted data block contains several peak detection measurements at once, and according to the needs of the user every now and then one of the blocks contains one extra spectrum, which can be adjusted by the "spectra refresh time" setting.

3.2.8 Use high speed mode (up to 2kHz) when streaming

In the X1000, onboard signal processing like background subtraction and peak detection with many FBG detection channels slows the microcontroller down to about 1kHz. Higher frequencies up to 2kHz can be achieved, however, if background correction is disabled. This can be done by enabling the "High speed mode". Beware that by doing so, measurement accuracy may be slightly affected; so one has to test if the signal quality is still sufficient.

3.2.9 Real time monitoring/debugging

With the blockwise streaming mode, every single successive measurement should be transferred, regardless of jitter or delays in data transmission. To make sure this really is the case with the actual configuration of devices and peripherals, when activating this tick box the transferred data (Temperature, wavelength or strain) of the first FBG sensor of each fiber port is exchanged by the internal measurement counter of the FiSpec device. This number increases from 0 to 255 repeatedly. If one wants to use this functionality permanently and not for testing purposes only, it is possible to just manually add an extra neglectable FBG detection channel at the beginning of the channel list via the settings window.

3.2.10 Manual override of exposure parameters

In specific cases it may be desired not to let the devices choose the exposure parameters according to a specific frequency by themselves, but to manually set them. In this case, here the averages and integration time can be chosen freely; pressing the "set average/time values of every connected device" then overrides all actual settings of all devices and sets the new values.

3.2.11 Saving currently active settings to devices

Pressing this button saves the current state (Autostart, streaming mode, peak channels, integration time, averages, zero values for onboard calculation, UART parameters, dark spectrum) of all connected devices to flash memory. BEWARE: no wear leveling is applied when saving, so this button is not to be used routinely, but only when really necessary. Each time the command is executed, an internal counter is incremented (value shown in "`#Schreibzugriffe_x`" after `p?>` command, see programmer's manual). After pressing the save-button, a user dialog opens to ask for confirmation.

<div style="border: 2px solid red; color: red; font-weight: bold;">
FiSens recommends not to exceed 50 saving processes in total during the lifetime of the device to avoid data corruption. Any "#Schreibzugriffe_x" values higher than 51 will void warranty.
</div>

3.3   Panel "Configuration=>Program settings"

This panel (see Fig. 25) offers different options to save measurement data to disk, tailor visualisation, change the program startup behavior and specify the UDP streaming settings.
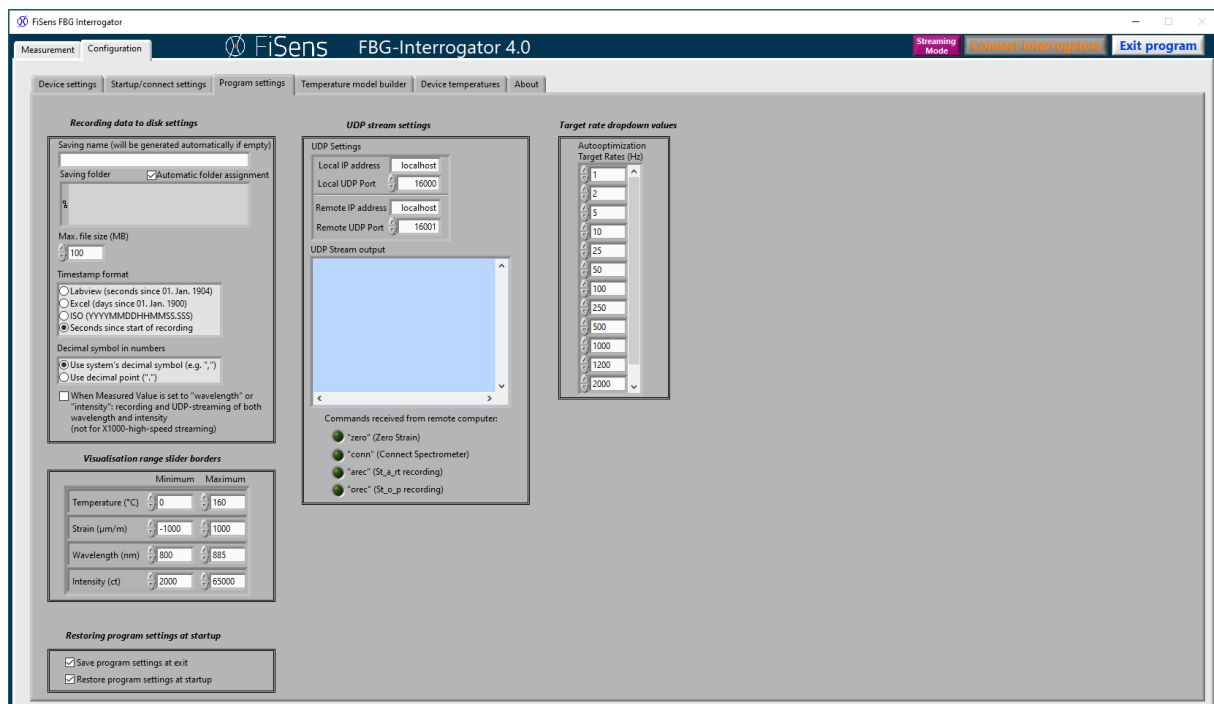
Fig. 25 Sub-panel „Configuration"=>"Program settings".

3.3.1   Recording data to disk

If FBG sensor planes are selected on the frontpanel, the realtime data can be saved to disk. If "saving name" is left empty, the main file name will be automatically generated out of date, time and data type (strain or temperature/intensity/wavelength). If "Automatic folder assignment" is activated, the files will be saved to the standard data folder with subfolders named after the current date (see chapter 1.2 for details). Elsewise, the user specified folder will be used.

Keep in mind that changes in file or folder names will come into effect as soon as a new recording starts. Recordings already active are not affected by changes.

The maximum file size can be set to any size supported by the used file system. If during measurement the file size is exceeded, a new file with the same main file name but incrementing trailing number will be generated.

Here also the format the time stamp and decimal point in the saved text files can be chosen. Further details about the file names and saving format are shown in chapter 4.2.

Beware that only data of selected sensor planes will be saved.

3.3.2   Visualisation range slider borders

On the front panel, the respective measurement value of a sensor plane is visualised by a certain colour, ranging rainbow wise from violet (minimum) to red (maximum). Here the range of the sliders

can be chosen. This settings are purely for visualisation purposes and do not influence the measurement results.

3.3.3   Restoring program settings at startup

By default, all program settings are saved to a certain binary file (described in chapter 1.2) when exiting the program and restored when starting the program again. If, for some reason, this behavior is not desired (for example, if experimental settings are chosen that should not be restored at the next start), this can be fine tuned by the options "Save program settings at exit" and "Restore program settings at startup".

3.3.4   UDP stream settings

The Fisens FBG interrogator 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.

To establish a connection, the local and remote connection details have to be provided here: 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 FBG-Interrogator listens on to get remote instructions. If the remote program resides on 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 (FBG-Interrogator program) and 16,001 (remote program); they can be changed if any collisions with other programs occur.

UDP streaming of measured data and remote control of the FBG-Interrogator software is actived by clicking the "UDP Stream" button at the front panel. 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 FBG-Interrogator program can be seen in real time in the "UDP stream output" window. The remote program on its part can send "Zero Strain", "Connect Spectrometer", "Start recording" and "Stop recording" instructions to the FBG-Interrogator program; the respective indicators light up shortly when incoming instructions are recognized.

The protocol of the UDP data stream is explained in detail in chapter 4.1.

Beware that only data of selected sensor planes will be sent. So firstly check if sensors are selected in case the connection does not seem to work.

3.3.5   Target rate dropdown values settings

The possible measurement rates of the target rate dropdown selector on the front panel can be tailored to the specific need of the user. For example, if anyone needs only low frequency temperature measurements, the unnecessary predefined frequencies can be removed here. If anyone, on the other hand, owns the X1000, the 2kHz setting might be useful. To remove or add entries in between two entries, right click on the table there and choose the according option.

3.4 Panel "Configuration=>Temperature model builder"

The nonlinear temperature/wavelength change relation depends on the glass fiber material used for the sensors and is approximated onboard by polynomial functions ("Temperature models"). These temperature models consist of one polynomial for the temperature=>wavelengthshift function and one polynomial for its inverse wavelengthshift=>temperature function. In this sub-panel the approximation of this temperature dependent wavelength-shift behaviour can be manually optimized for different scenarios, so that afterwards the resulting models match the behaviour of a certain glass fiber material in certain temperature ranges.
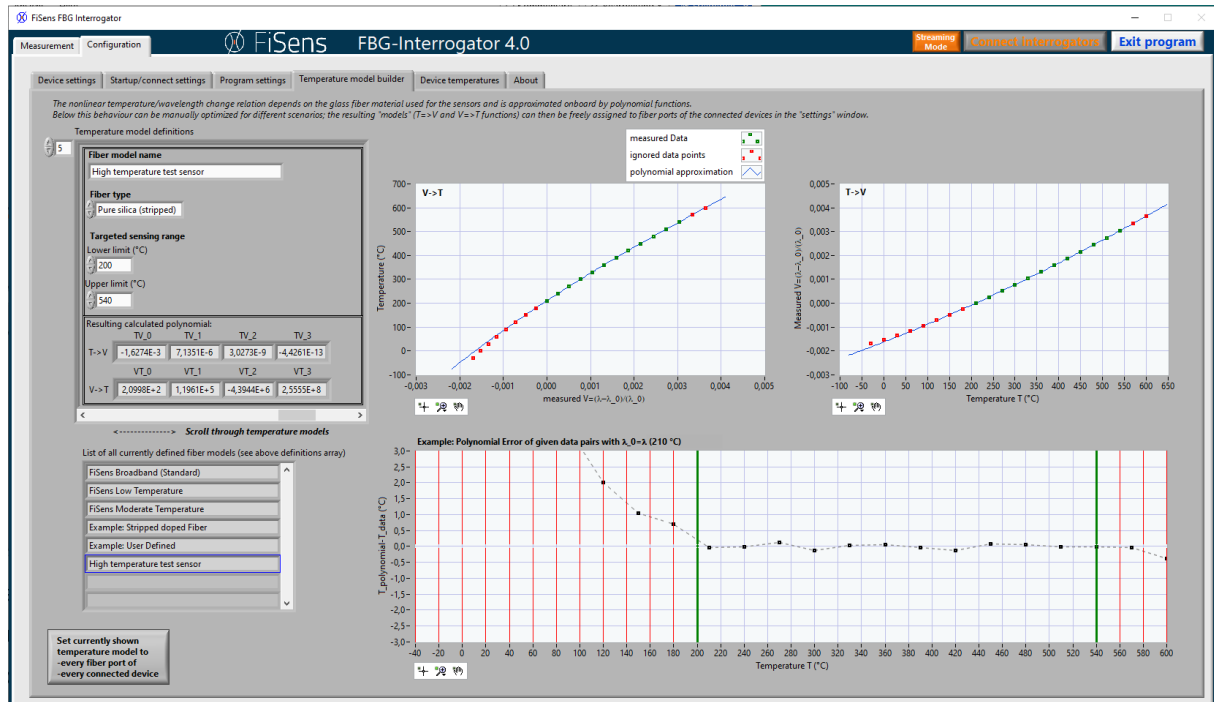

Fig. 26 Setting up a new temperature model.

The first three models in the list are predefined ones that can not be changed, followed by two arbitrary examples. To create a new model, either scroll the "temperature models definitions" array to the first empty position (counter "5" in the upper left corner), or click on the first empty position of the lower list array, which will be highlighted then by a blue frame. Both arrays are connected to each other, so if you scoll the upper one, the selection of the lower one will also change, and vice versa. In the upper array now a sensor name can be entered. This name will now appear in the "List of all currently defined fiber models" array, as well as in the settings window (see chapter 2.3.1).

The fiber type has to be chosen according to the one used in the sensor. For example, if the sensor has been manufactured for accuracy within a capillary (stainless steel, PEEK, etc.), the fiber will likely be made out of pure silica core fiber and the polyimide coating has been stripped off – hence choose pure silica (stripped) as fiber type.

Then the lower and upper limit of the desired temperature range is to be specified. As can be seen the right plots, a polynomial based on the fiber type and the temperature range will be automatically created. The data points in the diagrams are not synthetic ones, but based on real world data measured with the according fibers at FiSens GmbH, so slight irregularities may appear. Also the shown range is dependent on the data points available; with stripped pure silica, for example, there

are data points between -40°C…600°C (see Fig. 26), whereas for doped fiber the data ranges from -40°C…300°C.

Only the data points in the set temperature window are taken into account for the approximation (green dots in the upper two graphs of Fig. 26), so that the black polynomial curve aligns with the green dots; the others (red ones) are outside of the desired temperature range. The further they are away from the set temperature range, the more the polynomial differs from the data points. In the lower graph ("Polynomial error of given data pairs") is shown how much the the newly approximated polynomial would differ from the measured data points. As can be seen, outside of the temperature range (red hatched area outside of the green bars) the errors increase significantly. So sometimes it may be safer to choose a wider range when calculating the polynomial instead of going for the lowest possible error inside of the range.

If a special fiber type is used, or the sensor is mounted in a special way (for example, not freely moving), it is possible to do a very own calibration that matches exactly this sensor by just measuring the change of the back reflected wavelength while applying different temperatures to the sensor.
So when changing "Fiber type" to "Custom", an empty array appears that can be filled with the measured calibration data (see Fig. 27), either pairs of temperature/wavelengths or temperature/normalized wavelength shift.
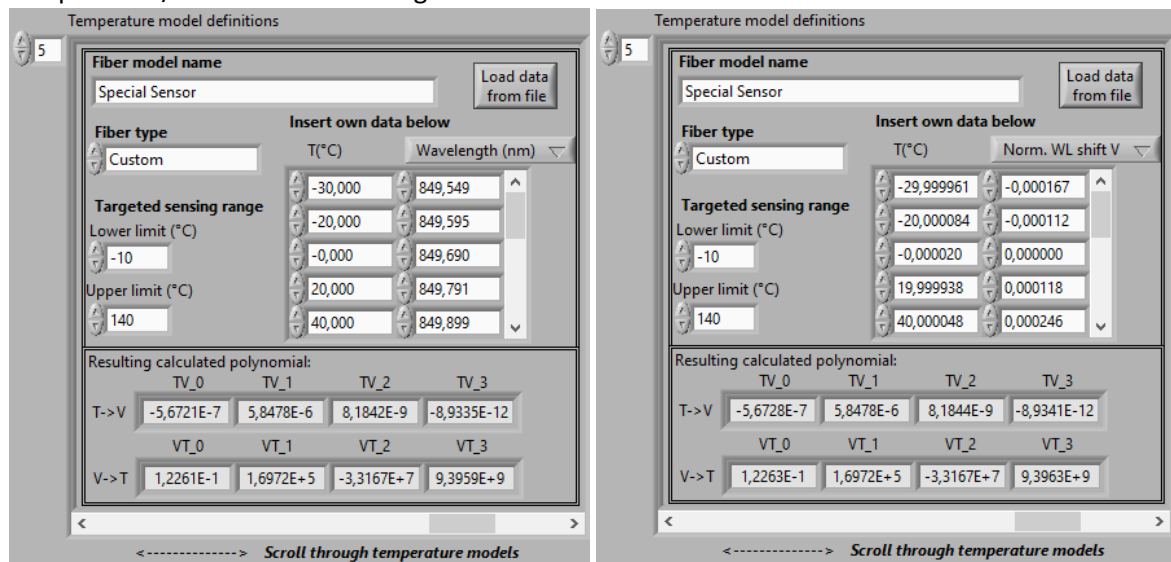
Fig. 27 Custom fiber type: inserting pairs of calibration temperature and wavelength (left) or temperature/normalized wavelength shift (right).

The data can either be typed in manually or loaded from a text file (Tab delimited). Now the model can be created as described above.

When exiting the program, this new model will be saved to the FBG-Interrogator configuration file on the computer, along with the other program settings. So as long as this file is not deleted, the fiber models will be available in FBG-Interrogator. If specific fiber models have to be used on other computers as well, this file can just be copied.

Keep in mind that only the fiber models currently stored into the FiSpec devices are used for the onboard calculations, regardless of what is shown here! So if one wants to send a fiber model to the spectrometer, there are two ways:

- If all fiber ports of all connected devices should use the currently shown fiber model, this can be accomplished by clicking the button on the lower left side.

- If different sensors mounted to different fiber ports should use specific fiber models, this can be done by transferring them in the "settings" window (see chapter 2.3.1).as well as in the settings window (see chapter 2.3.1).

Remember to store the spectrometer's settings to its flash memory if you want the newly set fiber model to persist.

3.5 Panel "Configuration=>Device temperatures"

At this panel the inner temperature of all connected FiSpec devices is shown (see Fig. 28). These values are derived by an electronic temperature sensor that is located inside the casing nearby both the CMOS sensor and the inner compensation FBG; therefore they are also used by the microcontroller for temperature compensation calculation purposes.
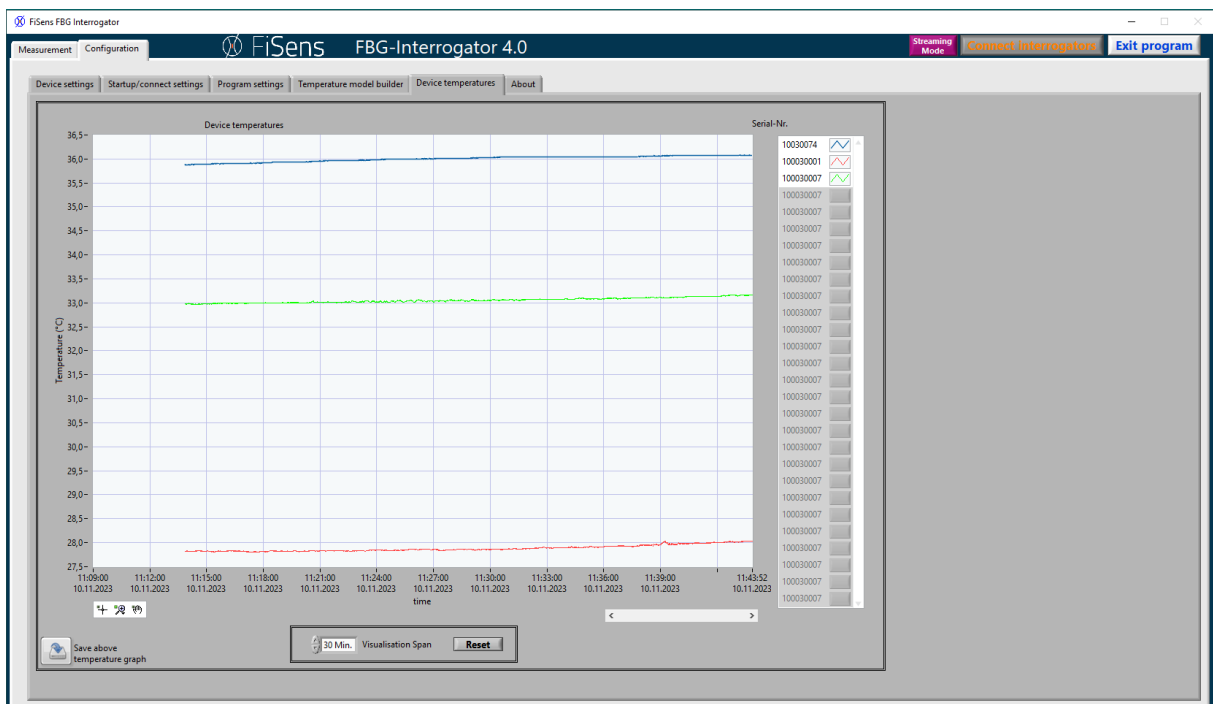
Fig. 28 Device temperature diagram.

This graph can be useful to determine if the device is already thermally stabilized. Also the influence of changing ambient temperatures can be seen here.

Fig. 29 Shortcut for saving actual device temperature diagram.

Next to the temperature diagram there are buttons like the one shown in Fig. 29. When clicking on it, the diagram is exported as both `*.png` graph file und the respective measured values as `*.txt` file to the standard saving folder. The filename will contain the actual time in hours, minutes and seconds:

```
xxh_xxm_xxs_device_temperatures.txt
xxh_xxm_xxs_device_temperatures.png
```

4 FBG-Interrogator communication protocol and file format

4.1 FBG-Interrogator UDP communication

When sending data to a remote program, data is transmitted as a text string. The format of decimal points and time are according to the settings in the "Program settings" tab (see chapter 3.3.1).

The following example shows the stream for three FBG sensors from two different FiSpec devices:

```
FBG-Interrogator data stream.
SN/MN/FN: Serialnumber/Multiplexnumber, Fiber port number.
Strain: [S]=µm/m; Temperature: [T]=°C; Wavelength: [W]=nm; Intensity: [I]=ct.
Time(s):42,519
SN/MN/FN:10030140/-/1
T3_22,47/
SN/MN/FN:40030001/-/2
S6_2,92/T10_50,46/
#
```

The header consists of the first three lines, in which the format and units are explained.

The fourth line shows the time stamp.

The information about every fiber port now consists of two lines:

- device number/multiplex number/fiber port number

- data of all selected sensors of this fiber port

Finally, the end of a time frame is marked by "#\r\n".

So in the above example:

device Number 10030140, fiber port 1:

   -Sensor number 3 is a temperature sensor (actual temperature: 22.47°C)

device Number 40030001, fiber port 1:

   -Sensor number 6 is a strain sensor (actual strain: 1.92µm/m)

   -Sensor number 10 is a temperature sensor (actual temperature: 50.46°C)

Remote programs can control the FBG-Interrogator program by sending short UDP strings (see Table 1). No termination characters are necessary because the whole received string is searched for known instructions. To date there are two instructions possible:

UDP instructions (FBG-Interrogator program)	
zero	Initiates "zero wavelength" processs
conn	Initiates reconnection of spectrometer
arec	Initiates start of recording
orec	Initiates stopping an ongoing recording

Table 1 UDP instruction set for FBG-Interrogator program.

zero

This is equivalent to clicking "Zero all" in the FBG-Interrogator program.

conn

This instruction activates the "Connect interrogators" button in the FBG-Interrogator program.

`arec`

This instruction activates the "Record to disk" button in the FBG-Interrogator program.

`orec`

This instruction deactivates the "Record to disk" button in the FBG-Interrogator program.

4.2 FBG-Interrogator file format

When recording temperature, strain, wavelength or intensity values, files are saved by default into the in chapter 1.2 described directory. All data files consist of plain ASCII characters; the columns are separated by TAB characters. Every line ends with line feed character \n. The decimal point and timestamp format can be set by the user (see chapter 3.3.1).

If a specific filename is given by the user like described in chapter 3.3.1, the files will be named accordingly. For example, a specified filename "`asdf`" results in the following files, according to which value unit ("Temp. or strain", "wavelength", or "intensity") is chosen at the moment of recording (see chapter 2.2.2):

```
asdf_intensity_001.txt
asdf_wavelength_001.txt
asdf_sensordata_001.txt
```

The trailing number (here: `_001`) increases as soon as the maximum file size is exceeded and a new file is generated (see chapter 3.3.1).

If no filename is specified, the file names will include date and time as in the following example:

```
2022-03-24_17-56-09_sensordata_001.txt
2022-03-24_17-56-09_wavelength_001.txt
2022-03-24_17-56-09_intensity_001.txt
```

The text file contains a header that consists of the first two lines:
Line 1 explains the format and units.
Line 2 declares the data colums starting at line 3 and consists of
- one time stamp and
- serial number/multiplex number/fiber port number/measured unit+sensor, one for each selected sensor

As an example, the file may show the following lines:

```
Tab delimited data. Strain: [S]=µm/m; Temperature: [T]=°C; Wavelength: [W]=nm;
                                                  Intensity: [I]=ct.
Time(YYYYMMDDHHMMSS.SSS)   10020179/-/1/T1     10020179/-/1/S2   40020423/-/2/T5
20220330092516,9141        31,8400             75,2739           30,9000
20220330092517,8984        32,0700             76,8101           30,8100
```

So the first measurement of the above example:
Timestamp: 30. March 2020, 9:25 o'clock (+16,914 seconds)
device number 10020179, not multiplexed, fiber port 1,
        - Sensor number 1 is a temperature sensor (actual temperature: 22.47°C)
        - Sensor number 2 is a strain sensor (actual strain: 75,2739µm/m)
device number 40020423, not multiplexed, fiber port 2:
        - Sensor number 5 is a temperature sensor (actual temperature: 30.9 °C)
Each of the following lines likewise consists of new data at a certain time.

The format of the spectra files ("Save spectra at refresh" button) is described in chapter 2.2.3. The spectra are saved to disk both as a `*.png` graph and as a text file. The filename consists of device serial number, Date, time, and fiber port number (for example, "`10020179_2022-03-28_11-29-07_0.txt`"). The first line in the text file consists of integration time (in milliseconds) and number of averages.

5   Changelogs

5.1   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 immeadiately 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* channel width; now: 0.25*)
-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. transmission=(value-1)*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 occuring 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

v10.1
-added: onboard Edge-FBG measurement functionality

v10.2

- For speed reasons, Edge calculations are now only executed when activated before (`EBs,x>` command added)

v10.3

- optimized linearization of peak detection (before: slight wavelength nonlinearities appeared when peaks crossed pixel borders)
- removed first derivative peak detection mode (command `PeM,x>` obsolete)
- supports devices with 1, 2, 3 and 4 fiber ports (before: only 1 and 4 fiber ports possible)

v10.4

- error bits are now also set in peak following mode if peak following is temporarily disabled (e.g. due to bad signal quality or extreme wavelength jumps)
- `e?>` command: fifth 32 bit number (until now reserved for future use) now contains more specific real time information about what kind of error (S/N ratio, over exposure, peak following, or reference FBG error) occurs at each fiber port in at least one peak detection channel.
- automatic periodic dark frame update (`ADBA,x,y,z>` command): for averages>1 the measured dark spectra are now averaged like normal spectra (until now: only single, not averaged frames, regardless of active averaging setting) before being low pass filtered.
- internal threshold for error detection adjusted for reference FBG channels

v10.5

-fixed: under certain circumstances, stacked systems ignore too long commands (three variables, for example `Ke,x,y,z>`)
-improved stability of peak detection at bad signal/noise ratio or with peaks overlapping the given channel borders
-supports FiSpec X124 devices

v10.6

-fixed: if the UART frequency of the connected host system (the converter box used for multiplexed stacked FiSpec devices, for example) is too far off, but communication is still possible, and therefore the UART transmission error rate is too high, both the FiSpec's UART and FTDI USB-interface lock down, and communication is not possible anymore without repowering the device
-inbuilt quartz oscillators are now supported ("`#Qv,1`" is then shown in the parameter string) if available

v10.7

-peak detection optimized: with very noisy signals or when no sensors were attached, sometimes wavelength=0nm or the corresponding extreme temperature/strain values were randomly transmitted for some peak channels

5.2 FBG-Interrogator changelog

v 2.0 (November 2021)
-first officially released version

v 2.01 (December 2021)
-fixed filenames when saving intensities
-added: support for wireless LAN devices

v 2.02 (December 2021)
-fixed: channel border corruption when setting FBG channels in settings window

v 2.03 (December 2021)
- optimized delays for network communications

v 2.04 (January 2022)
- fixed: truncated multiplex-numbers in information panel for stacked single fiber devices

v 2.05 (February 2022)
- now also supports devices with two or three fiber ports
- Changes in "signals" window (hiding/selecting sensors)

v 2.05/2.06 (February 2022)
- code optimizations

v 2.07 (March 2022)
- added info text box in spectra PNG files

v 2.073 (March 2022)
- code optimizations
- added "Show Temp." and "Show Strain" buttons in visualization window

v 2.08 (April 2022)
- calculation speed optimized

v 2.09 (June 2022)
- shows new global fiber port error codes of firmware 10.4 when clicking signal level indicator
- errors of individual sensors are shown separately (red "E" dots)
- added calibration readjustment functionality (settings window)

v 2.1 (June 2022)
- Saving folder can be set manually ("Automatic folder assignment" tickbox in Program settings)

v 2.11 (June 2022)
- Automatically assigned saving folder path is now shown

v 2.20 … 2.23
-experimental versions

v 2.24 (January 2023)
-Temperature model builder added (for defining fiber dependent temperature polynomials)
-Added: Temperature models can be assigned to fiber ports in Settings window

v 2.25 (April 2023)
-Settings window: device's optoelastic constant for strain measurements is shown and can be altered

v 2.26 (April 2023)
-fixed: outdated number of flash writes may show in settings window after "save to flash"

v 2.27 (April 2023)
-Settings window: device's external UART baudrate can be altered

v2.28 (May 2023)
-fixed: when setting onboard peak detection channels (i.e., clicking "set manually"/"equidistant auto-set"/"adaptive auto-set" in settings window, or clicking button "Set the same FBG channels array from file" in configuration=>Device settings), channels were not completely transmitted when connected via USB port while EtherCAT is activated (X100T).

v3.0 (June 2023)
- supports now the new blockwise streaming protocol (for example, used in FiSpec X1000). When all connected devices support high speed streaming, the "Streaming mode" button on the frontpanel turns yellow and only block wise streaming is available instead of the old streaming mode.
-„disable streaming mode at connection" option removed (Panel "Configuration" => "Startup/connection settings"); streaming will now always be disabled when connecting.
-„Auto-Refresh" time and switch moved to the right upper part of the frontpanel. Labelling changes now according to active streaming/non streaming mode.
-The „Target rates" for auto-optimization can now be tailored according to the user's requirements (see panel „Configuration"=>Program settings"=> "Target rate dropdown values").
-„Visualisation span" of the device temperature graph now allows for up to 20h visualization (see panel „Configuration"=>Device temperatures").
-state of the „UDP-Stream" button is now also saved to program settings file at exit
-if desired so, both wavelength+intensity are recorded and streamed via UDP when "Measured Value" dropdown value is set to either "Wavelength" or "Intensity" (selectable in "Configuration"=>"Program settings"=>"Recording data to disk settings"=>"When measured value is set to…" settings).
-data recording can be switched on/off by new UDP commands ("arec"/"orec")
-fixed: flickering of sensor panel while refreshing spectra
-devices that show timeout more than 5 times in a row are automatically disregarded to avoid slowing down the measuring process of the remaining ones.
-Temperature model builder: custom fiber type now also supports normalized wavelength shift data instead of absolute wavelengths.

v3.1 (September 2023)
-fixed: when setting polynomial parameters using "fiber type: custom" and "norm. WL shift V" as y-data format, wrong parameters could be set in the device under certain circumstances.

v4.0 (November 2023)

-High-speed blockwise streaming mode supported

-Spectrometers with two sensors (X144) supported (two different integration times shown)

-Fixed: while in settings window, the last measured data points in the main window were repeated and subsequently also shown in the graphs, recorded to files and transmitted to UDP in case these functions were activated.

-added "2 sec." setting to visualization span

-Enlarged "selected sensors" window: Pause button added; y-axis labelling according to the units of the selected sensor values.

-Adaptive auto-set in settings window optimized (two new buttons appear in the graph; results of modifying the threshold is shown before resuming)

-added integration time and number of averages information in the spectra files (first line in text file; see chapter 2.2.3)

6   Document revision changelog

Rev. 3 (01/2024)

-FiSens logo changed

-Document revision list added

-Firmware up to 10.7 added to changelog