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Glaz LineScan-II

High-speed linear array cameras

- Low-noise
- 16-bit resolution
- Data compression
- Large memory buffer
- High-speed USB interface & USB-powered
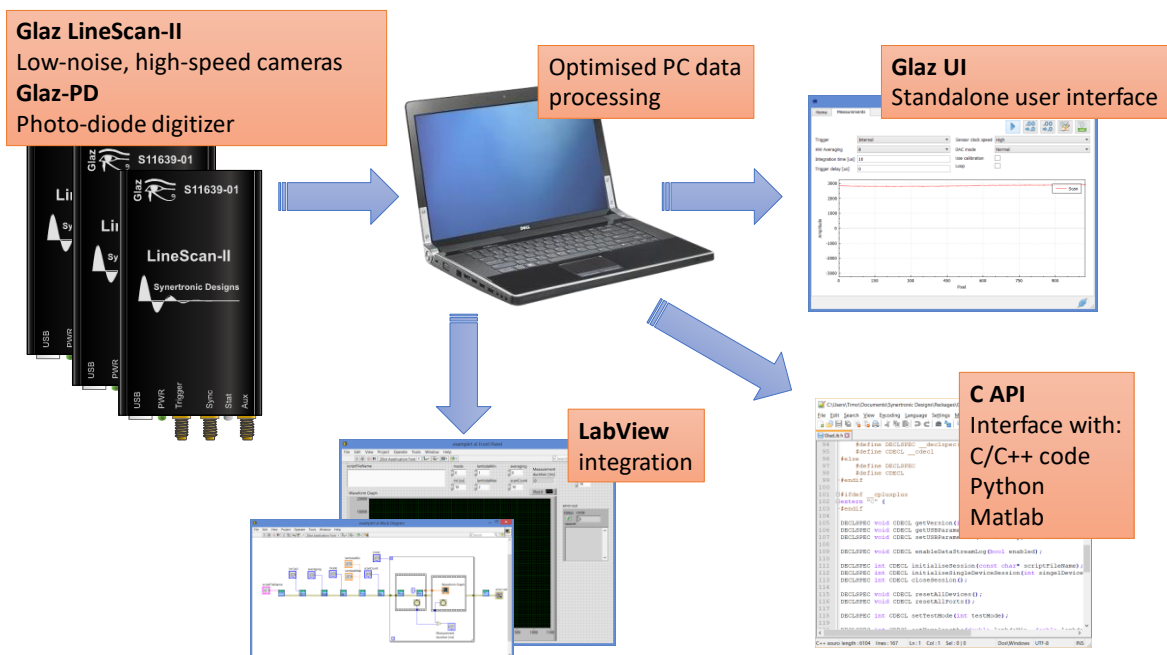- Flexible XML-based configurations

Overview

Glaz LineScan-II is a low-noise camera with 16-bit resolution. Extremely low noise-levels can be obtained by a selection of hardware and/or software averaging modes. Combined with powerful PC-based data processing software, a multi-camera measuring system can be configured quickly and effortlessly.

Glaz LineScan-II cameras are highly configurable at runtime. They support two timing modes (*PulseSync* and *TimeFill*), configurable resolution and two configurable IO ports in addition to a dedicated trigger port.

Glaz LineScan-II cameras have large onboard memory buffers to capture every line. A lossless data compression algorithm is used to reduce memory requirements and USB bandwidth with a compression ratio of between 2:1 to 4:1.

Glaz UI (a stand-alone application) or LabView can be used to configure and communicate with the cameras. Measurements with single- or multi-camera configurations can be configured, using XML-based script files. This provides a flexible way to define calculations, that need to be performed on the measured data. All data processing is performed in optimised, multi-threaded libraries, thereby providing the best possible performance. *Glaz API* is a C-style library for interfacing with your own code written in Python, C/C++ or Matlab.

Glaz LineScan-II
Low-noise, high-speed cameras
Glaz-PD
Photo-diode digitizer

Optimised PC data processing

Glaz UI
Standalone user interface

LabView
integration

C API
Interface with:
C/C++ code
Python
Matlab

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Specifications

Characteristic	Value	Unit
PC Interface		
PC interface	USB 2.0 (high-speed)	
Data transfer rate[1]	>10	MB/s
Maximum USB cable length	3	m
Linear sensor		
Sensor type	CMOS	
Supported sensors	Hamamatsu S12198-1024Q Hamamatsu S10453-1024Q Hamamatsu S11639 Hamamatsu S11639-01	
Optical integration time	2 – 400,000	µs
Hamamatsu S12198-1024Q/S10453-1024Q		
Pixel count	1024	
Maximum line rate	9,000	lines/s
Spectral response range	200 – 1000	nm
Noise level (single scan)	<400	µOD [2]
Noise level (256 averaged scans)	<25	µOD
Dynamic range[3] (single scan)	>2,500	
Dynamic range (256 averaged scans)	>40,000	
Hamamatsu S11639-01		
Pixel count	2048	
Maximum line rate	4,500	lines /s
Spectral response range	200 – 1000	nm
Noise level (single scan)	<280	µOD
Noise level (256 averaged scans)	<18	µOD
Dynamic range (single scan)	>3,500	
Dynamic range (256 averaged scans)	>55,000	
Digitizer		
Resolution	16	bit
Full-scale reading	65535	
ENOB (effective number of bits)	13.5	bit
Drift	100	ppm/^{O}C
Total analogue front-end noise level	<300	µV$_{RMS}$
Internal memory	96	MB
External trigger		
Signal type	5V-TTL	
Trigger edge	rising	
Positive-going threshold voltage	2.8	V
Negative-going threshold voltage	2.0	V
Minimum trigger pulse width	1	µs
Programmable trigger delay	0 - 200	ms
Programmable trigger delay resolution	0.1	µs

Table 1 Specifications for *LineScan-II*.

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[1] Using dedicated USB 2.0 port.
[2] OD is the relative amplitude with respect to full-scale value.
[3] Dynamic range is defined as the ratio of the full-scale value and the RMS noise value.
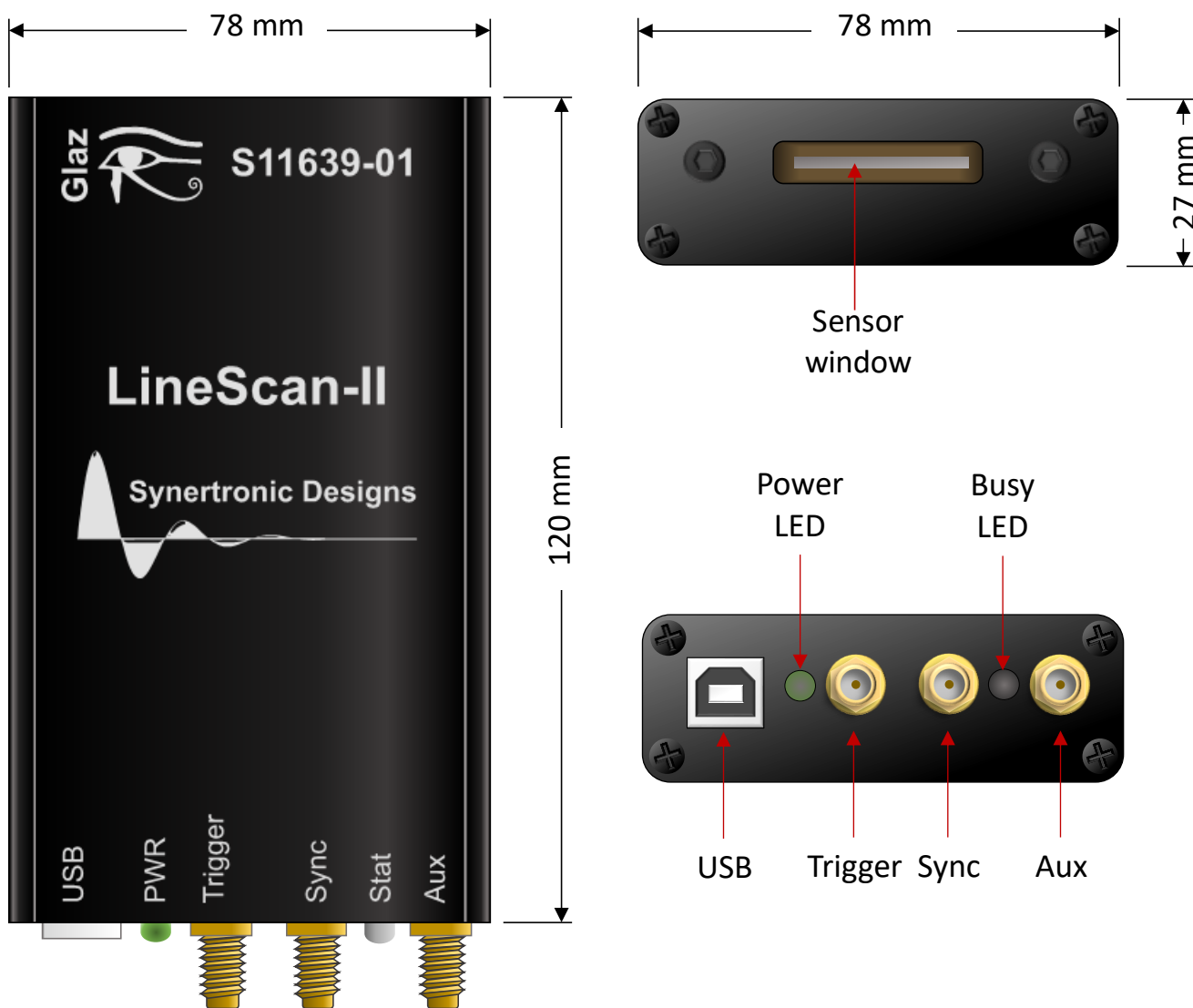
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Hardware description

Dimensions

Figure 1 Mechanical dimensions and legend.

Ports

Port	Type	Dir	Function
USB	USB-B	–	Data connection to a PC. Also provides the camera with power.
Trigger	SMA	I	External trigger input.
Sync	SMA	I/O [4]	Configurable open collector IO mainly used for.
Aux	SMA	I/O [5]	Configurable auxiliary input/output

Table 2 Connectors.

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[4] Open collector input/output
[5] Configurable as TTL output or as high-impedance TTL input

LEDs

LED	States	
Power LED	off	no power
	green	camera has power.
Stat LED	off	idle
	green	waiting for trigger
	green to red	triggered and busy scanning

Table 3 LEDs.

The colour of the *Stat* LED is an indication of how busy the cameras is. When the camera is not busy (i.e. not triggered) the LED will be green. When the camera is working close to its maximum line rate, the LED will be red. For lower line rates, the camera will be yellow.

not busy / wait for trigger	Low scan rate	Medium scan rate	Maximum scan rate

Figure 2 Ready/Busy LED colour legend.

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Functional description

Connecting cameras to a PC

Cameras are connected to a PC via USB interfaces. *Glaz LineScan-II* cameras are USB 2.0 high-speed devices.

If a PC has a limited number of USB ports, it is possible to use an external USB hub. Up to two cameras can be connected to a single USB 2.0 hub without significant reduction in the data transfer rate. It is possible to connect more than two cameras to a single USB 2.0 hub, but this can reduce the maximum data transfer.

> ⓘ Use a self-powered USB hub, when connecting more than two cameras to the USB hub.

Measurement sequence

The measurement sequence can be broken into three main states:

- *Initialise*
  After the camera is connected to a PC, it enters the *Initialise* state. The camera loads default settings and programs the internal FPGA.

- *Idle*
  After initialisation the camera enters the *Idle* state. The sensor clock and internal trigger generator is running, but the camera is not performing any measurements.

- *Active*
  When a measurement command is sent from the PC, the camera enters the *Active* state. The camera uses the current configuration to captures a given number of lines. After the lines were captured, the camera returns to the *Idle* state. For each line capture, the camera cycles through a set of states.

  - *Wait*
    The camera waits for the next trigger.

  - *Integrate*
    When a trigger is received, the camera enters the *Integrate* state. During this period the sensor integrates the photo current.

  - *Data read-out*
    After integration, the analogue output signal from the sensor is digitised. The digital data is compressed and streamed via the internal buffer and USB to the PC. After the data-read-out the camera returns to the *Wait* state.
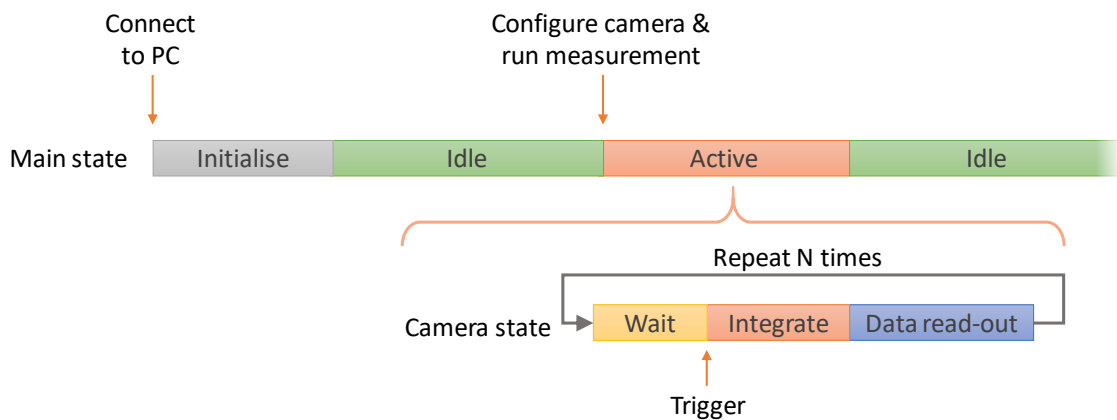

Figure 3 Measurement sequence.

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Camera clock speed

The internal sensor clock of the camera is operated at the maximum allowable frequency. Below is a list of sensor pixel clock frequencies:

Sensor	Clock frequency
S11639-01	10 MHz
S10453	10 MHz
S12198	10 MHz

Table 4 Sensor pixel clock.

Data compression and resolution

The *LineScan-II* features a lossless data compression algorithm. The compression algorithm utilises delta compression and the compression ratio typically ranges from 50% and 75%.

The resolution can also be specified. The resolution is the number of bits used to digitise the sensor values. The following resolution settings are supported: 16-bit, 14-bit, 12-bit and 10-bit.

The table below gives an estimate of the packet size per line (a compression ratio of 75% is assumed):

Resolution	Line packet data size [Byte]		
	1024 pixels	2048 pixels	4096 pixels
16	1552	3088	6160
14	1360	2704	5392
12	1168	2320	4624
10	976	1936	3856

Table 5 Line packet data sizes.

Data FIFO buffer

The *LineScan-II* features a 96 MB onboard FIFO[6] buffer. Compressed line data is written into the FIFO buffer. The data is then read from the FIFO buffer and streamed via USB to the target PC. The FIFO buffer ensures that every line is captured, irrespectively of the USB transmission speed.
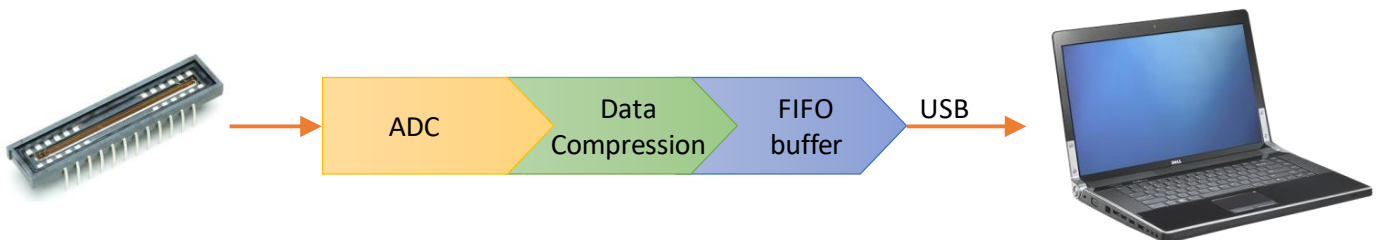

Figure 4 Data flow.

If USB transmission is extremely slow, the FIFO buffer might become full. When the FIFO buffer is full, lines might be skipped. The maximum number of lines that can be stored in the FIFO buffer is given in the table below (a compression ratio of 75% is assumed).

Resolution	FIFO capacity [number of lines]		
	1024 pixels	2048 pixels	4096 pixels
16	64900	32600	16300
14	74000	37200	18700
12	86200	43400	21800
10	103100	52000	26100

Table 6 FIFO capacity.

Under normal conditions, data is transmitted from the FIFO buffer at sufficiently high speeds and the probability of a buffer-full condition is low.

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[6] FIFO = first in first out

Triggering cameras

The *LineScan-II* offers three trigger modes:

- Internal trigger
- External trigger
- Burst trigger

Internal trigger

When running in internal trigger mode, no external trigger should be connected to the camera. In this mode, the trigger signal is generated internally by the camera itself. The internal trigger frequency is configurable. Below is a list of supported trigger frequencies:

Sensor	Internal trigger frequency
S11639-01	0.1 – 4600 Hz
S10453/S12198	0.1 – 9000 Hz
S13496	0.1 – 2300 Hz

Table 7 Internal trigger frequencies.

External trigger

Each scan is started after an external trigger pulse is applied to the *Trigger* port (see "IO ports" for more information).

Trigger delay

A trigger delay can be specified between the positive going edge of the trigger pulse and the start of the sensor integration period. The delay can be specified with a resolution of 0.1 µs and can be set between 0 and 200 ms. When a delayed trigger is received while the camera is still busy, this trigger will be ignored.
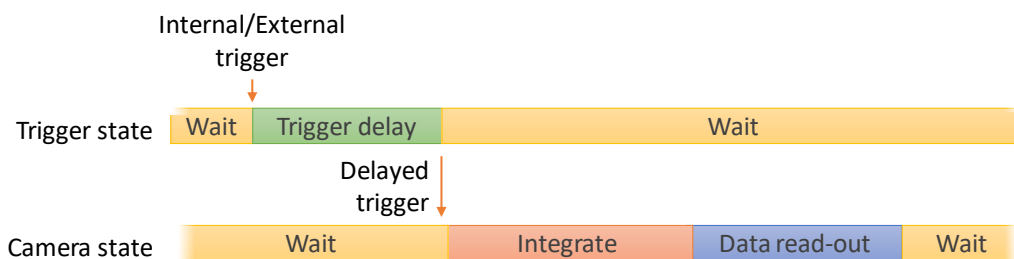

Figure 5 Trigger delay.

Burst trigger

The camera is armed and then waits for an external trigger. On the positive going edge of the external trigger, the camera enters the active state and uses the internal trigger generator to capture a given number of lines at the specified internal trigger frequency.
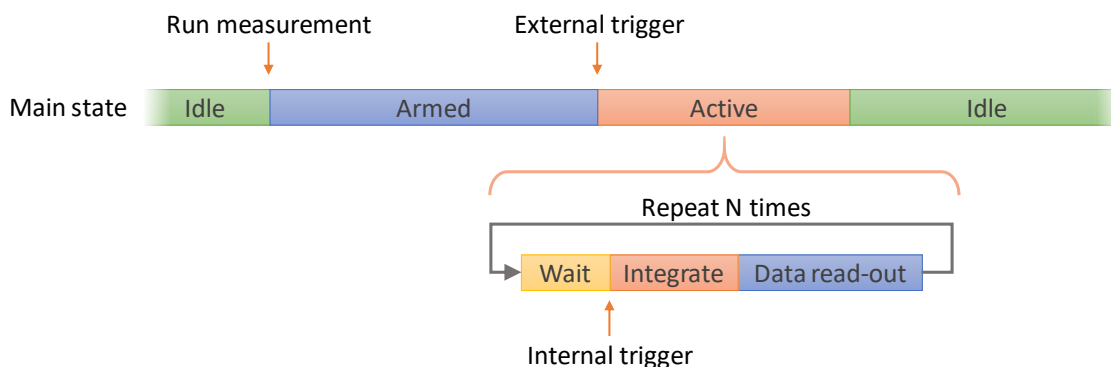

Figure 6 Burst trigger sequence.

IO ports

The LineScan-II provides three IO ports:

- Trigger
- Sync
- Aux

Trigger (input)

The *Trigger* port is a dedicated input port. The *Trigger* port is exclusively used as trigger input. See "Triggering cameras" for more information. The equivalent port model is shown below:
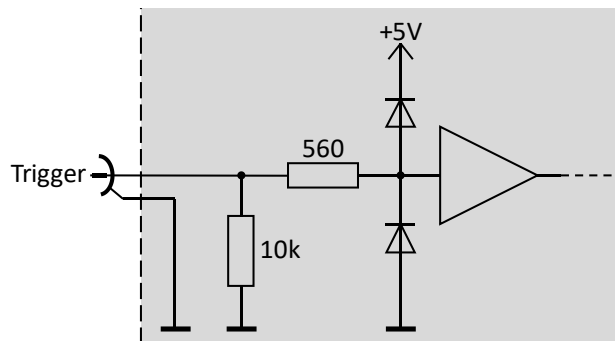

Figure 7 Trigger port model.

Sync (open collector input/output)

The *Sync* port is an open-collector input/output port. The equivalent port model is shown below:
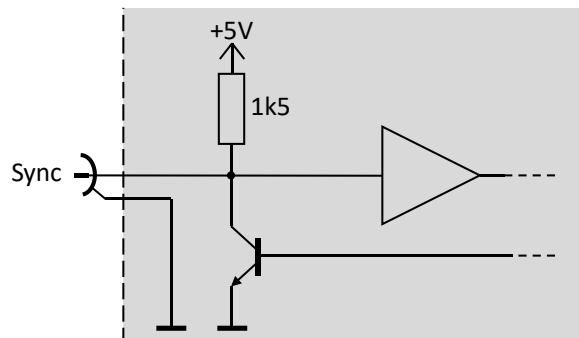

Figure 8 Sync port model.

⚠️ In *PulseSync* mode, the *Sync* port is used <u>exclusively</u> for multi-device synchronisation (see "PulseSync and TimeFill" for more information).

In *TimeFill* mode the *Sync* port supports the following output functions:

- Busy
- Integration window
- Trigger
- Cycle counting

Aux (input/output)

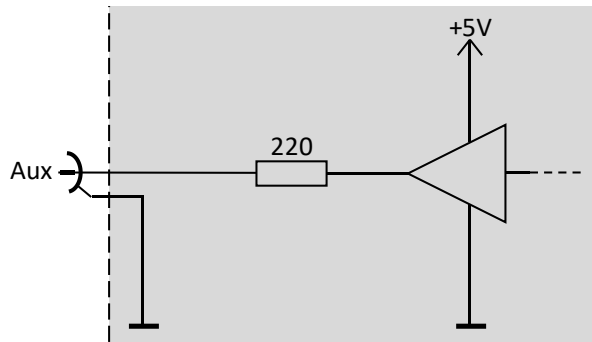The *Aux* port is an input/output port. The equivalent port models are shown below:

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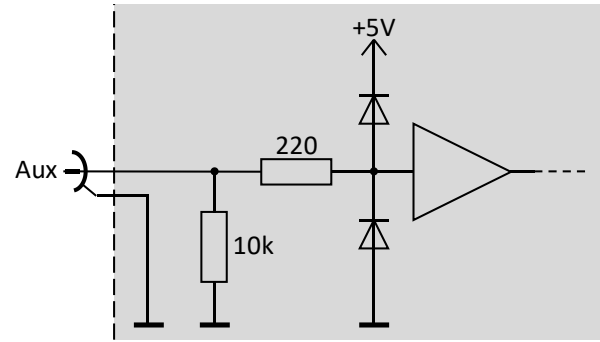
Figure 9 Aux port output model.

Figure 10 Aux port input model.

In output mode the *Aux* port is configured as a low-impedance 5V TTL output. The *Aux* port supports the following output functions in both *PulseSync* and *TimeFill* modes:

- Busy

- Integration window

- Trigger

- Cycle counting

In input mode the Aux port is configured as a high-impedance 5V TTL input with over-voltage protection. The *Aux* port state is captured at the beginning of each sensor integration window. The captured state is passed as meta-data together with the sensor line data to the PC.

IO port output functions

The following output functions are supported:

- Busy

- Integration window

- Trigger

- Cycle counting

> ℹ Outputs can also be configured to active high or active low.
> The descriptions below assume active high configuration.

Busy

The output is asserted high when the sensor integration windows starts and kept high until the integration window and data read-out is completed.

Integration window

The output is asserted high when the sensor integrations windows starts and kept high until the integration is completed.
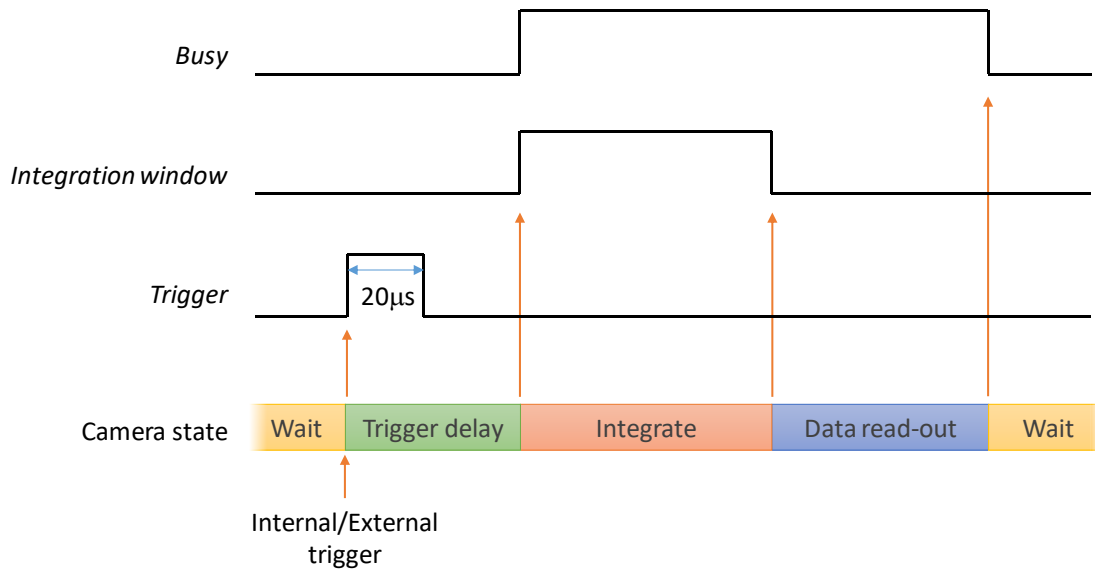
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Figure 11 *Busy, Integration window* and *Trigger* output functions.

Trigger

This output functions relays the internal trigger signal to the target output port. On the rising edge of each trigger signal a 20 μs wide pulse is generated at the target output port. The relayed trigger signal depends on the trigger mode. See the table below and "Triggering cameras" for more information.

Trigger mode	Trigger output
Internal	Internal
External	External
Burst	Internal

Table 8 Trigger output relay.

> *i* The *trigger* output function will generate a continuous output, even if the camera is idle.

Cycle counting

For cycle counting two output ports are used:

- Cycle start output
- Cycle running output

The cycle counter is incremented at the rising edge of each external or internal trigger pulse. When the cycle counter reaches the cycle TOP value, the counter is reset and starts counting from1 again. The cycle counter value is passed as meta-data together with the sensor line date to the PC.

The *Cycle start* output pulse is generated at the rising edge of the internal/external trigger pulse and when the cycle counter = 1.

The *Cycle running* output pulse is generated at the rising edge of the internal/external trigger pulse and when the cycle counter > 1.

Cycle counting can be used to cycle experimental conditions (for example: light sources) through a set of states.
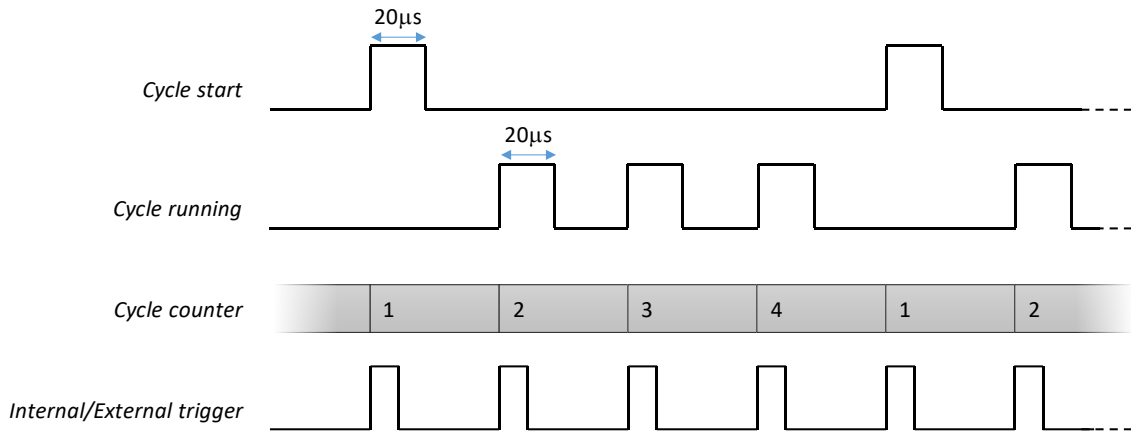
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Figure 12 *Cycle counting* example with cycle TOP = 4.

Integration time

During the integration time, the photo-current from the CMOS sensors will be integrated. The integration time can be set between 2 and 2000 μs. For short-pulse laser applications, the preferred integration time is 5 μs.

Single-camera configuration

In a single-camera configuration only a single camera is used. When external trigger mode is used, the camera must be provided with a trigger signal via the *Trigger* port.
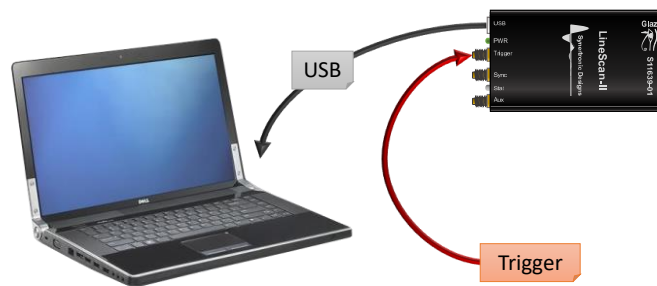

Figure 13 Single-camera configuration.

Hardware and software averaging

Averaging is a technique for reducing noise levels. *Glaz LineScan-II* provides two ways to average scans: hardware and software averaging.

Hardware averaging is performed on the camera. The number of scans to average can be set to: 1, 2, 4, 8, 16, 32, 64, 128 or 256. The camera will average the raw sensor data for the given number of scans. Only the final averaged result is sent to the PC. This is a useful technique to reduce the required USB bandwidth and processing speed of the PC.

Software averaging is performed on the PC. The difference compared to hardware averaging, is that the calculation result of the scanned data (i.e. processed data) is averaged. Hardware and software averaging can be combined to reduce noise and the required bandwidth and processing speed of the PC.

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Hardware averaging ($N_{a,HW}$):
Scans are averaged by hardware on the camera. Settings: 1, 2, 4, 8, ... , 4096

Software averaging ($N_{a,SW}$):
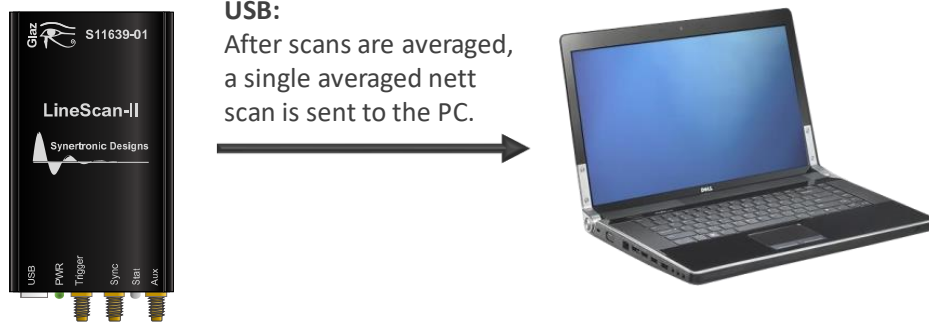Averaged scans are processed by the PC. Processed results can again be averaged.

USB:
After scans are averaged, a single averaged nett scan is sent to the PC.

Figure 14 Hardware and software averaging.

Software pixel binning

In the latest software, binning can be enabled. Binning calculates the average of 2 or 4 adjacent. This is not a moving average. Pixels are grouped into adjacent sets of 2 or 4 pixels and the average of each groups is calculated. As a result, binning reduces the effective number of pixels of the linear array:

Binning	Pixel averaging groups	Effective number of pixels
2-pixel	[0,1], [2,3], [3,4], …	½ $N_{p,sensor}$
4-pixel	[0,1,2,3], [4,5,6,7], [8,9,10,11], …	¼ $N_{p,sensor}$

Table 9 Pixel binning.

Noise

There are several ways to define the dynamic range of a camera. In this manual, the dynamic range D is defined as the ratio of the sensor full-scale A_{FS} value and the noise RMS value A_{RMS}:

$$D = \frac{A_{FS}}{A_{RMS}}$$

In order to decrease the noise level and increase the dynamic range, averaging can be used. The RMS noise level of an averaged signal is reduced by the square root of the number of averaged scans:

$$A_{avg,RMS} = \frac{A_{RMS}}{\sqrt{N_a}}$$

, where N_a is the number of averaged scans.

Pixel binning further reduces the noise level:

$$A_{avg,binning,RMS} = \frac{A_{avg,RMS}}{\sqrt{N_b}}$$

, where N_b is the level if binning (e.g. 2 or 4).

Drift

Drift of the camera sensor becomes visible, when performing low-noise measurements with a large number of averaged scans. When averaging more than 256 scans, the noise level drops below the camera drift. Drift is mainly cause by temperature changes of the camera sensor. This is more pronounced during the first 15 minutes after the camera is power up. In Figure 15 the drift of the average sensor reading as a function of time is given. The drift is expressed relative to the final average sensor reading after 30 minutes. A change of up to 2% can be expected during the first 15 minutes after power-up.
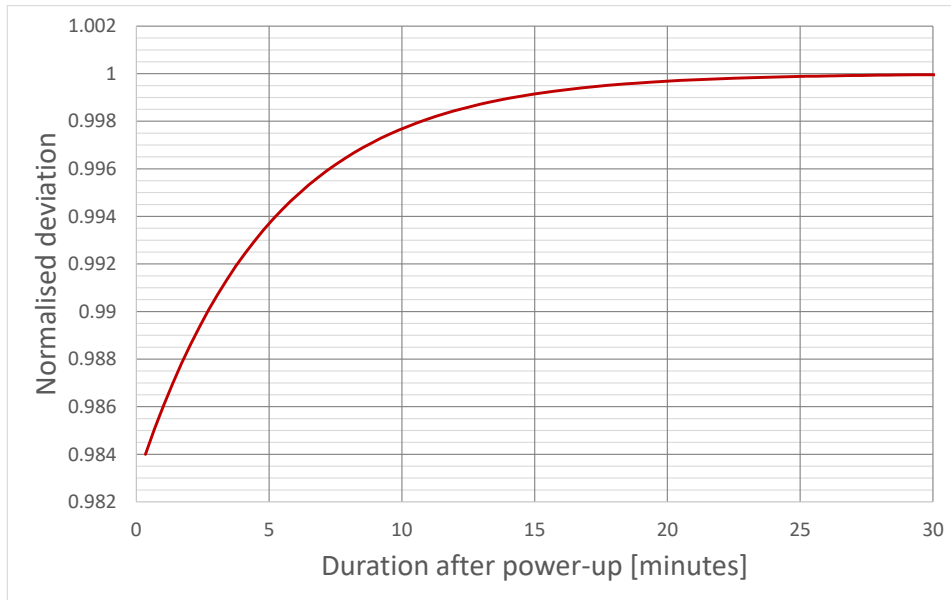
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Figure 15 Drift after power-up.

In order to reduce the effect of drift, the camera should be given at least 15 minutes to warm up. In addition, the camera sensor should be shielded from air drafts and room temperatures should be kept constant. It is possible to compensate for drift by performing a background measurement in regular intervals and subtracting this background from measurements.

Photoresponse nonuniformity (PRNU)

The pixels on a linear optical array are not identical. Each pixel has a different offset and gain. *Glaz UI* supports offset calibration per pixel. Gain calibration is also supported, but is not recommended. Calibrations are stored on the camera. A typical PRNU is shown in Figure 16.

Several averaged scans (with 256 hardware averaging) were taken and plotted. Only the data from the first 128 pixels is shown. Note: the resulting dark red trace is not noise, but the sensor PRNU. The noise level for each pixel is below the PRNU and the differences in gain and offset of each pixel is clearly visible.
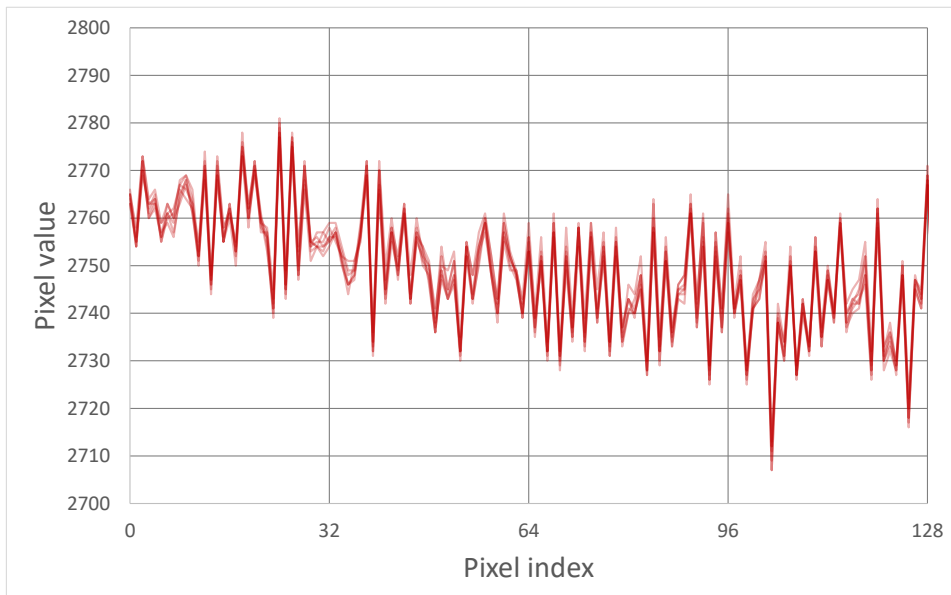

Figure 16 Example of PRNU.

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PulseSync and TimeFill

Glaz LineScan-II can be configured at run-time to use one of two timing modes: PulseSync or TimeFill. The most notable differences between the two timing modes are:

- Sensor read-out scheme

- *Sync* port functions

Sensor read-out schemes

The sensor integration period and the data read-out can either be interleaved or non-interleaved.

PulseSync – read-out scheme

PulseSync uses the non-interleaved read-out scheme. One integration and read-out cycle must be fully completed, before the next cycle can start. This is especially important for multi-camera systems to ensure reliable synchronisation.
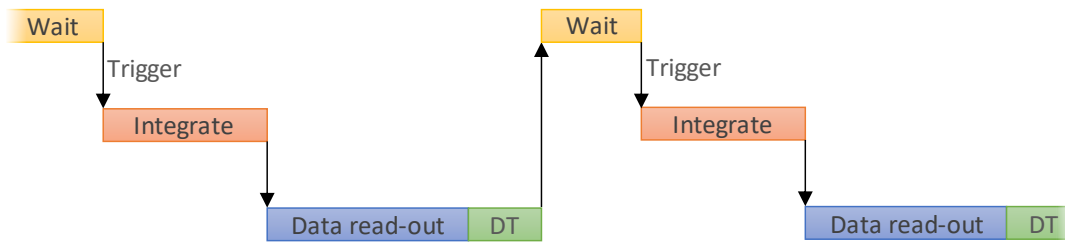
Figure 17 *PuleSync*: Non-interleaved read-out scheme

TimeFill – read-out scheme

TimeFill uses the interleaved read-out scheme. The next integration cycle can start even before the previous data read-out is completed. With this scheme, very high temporal fill factors can be achieved. Multi-camera synchronisation is possible but cannot be guaranteed.
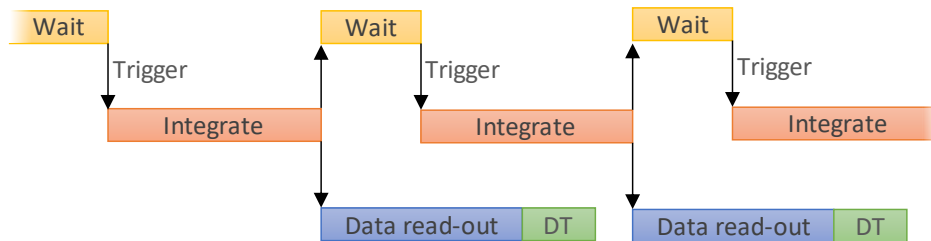
Figure 18 *TimeFill*: Interleaved read-out scheme

Sync port functions

In *PulseSync* mode the *Sync* port is exclusively used for synchronisation between *Glaz LineScan* cameras and *Glaz-PD* devices. For more information see "*PulseSync*: Multi-camera configuration and synchronisation" and "*PulseSync*: Combining Glaz LineScan-II and Glaz-PD devices".

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Measurements and scripting

Script file structure

The calculations that need to be performed by the PC with the measured data is defined by XML script files. A typical script file is shown in Figure 19.

```
<!DOCTYPE GlazScript>
<config>
    <camera serial="SYBP005010001" number="1" master="1"/>    Camera definitions
    <preprocessor camera="1" type="calibrate"/>                Pre-processing steps
    <preprocessor camera="1" type="subtract_background"/>
    <calculation name="Camera 1" keepscans="1">               Calculations
        <measurement camera="1"/>
    </calculation>
</config>
```

Figure 19 XML script file.

A script file consists of three sections:

1. Camera definitions:
   Each camera used for the measurement must be listed here.

2. Pre-processing steps:
   The pre-processing steps for each camera listed in the camera definitions must be specified.

3. Calculations:
   Any number of calculations can be specified. Each calculation can use the pre-processed results of one or more cameras.

Measurement data flow

Figure 20 depicts a multi-camera configuration with three cameras, two pre-processing steps for each camera and two calculations. Hardware averaged scans are sent from each camera to the PC via USB. The scans are then passed through the pre-processing steps. Data reception and pre-processing are performed on separate threads for each camera. On a quad-core PC, this would imply that the data from each camera is pre-processed on a separate core.
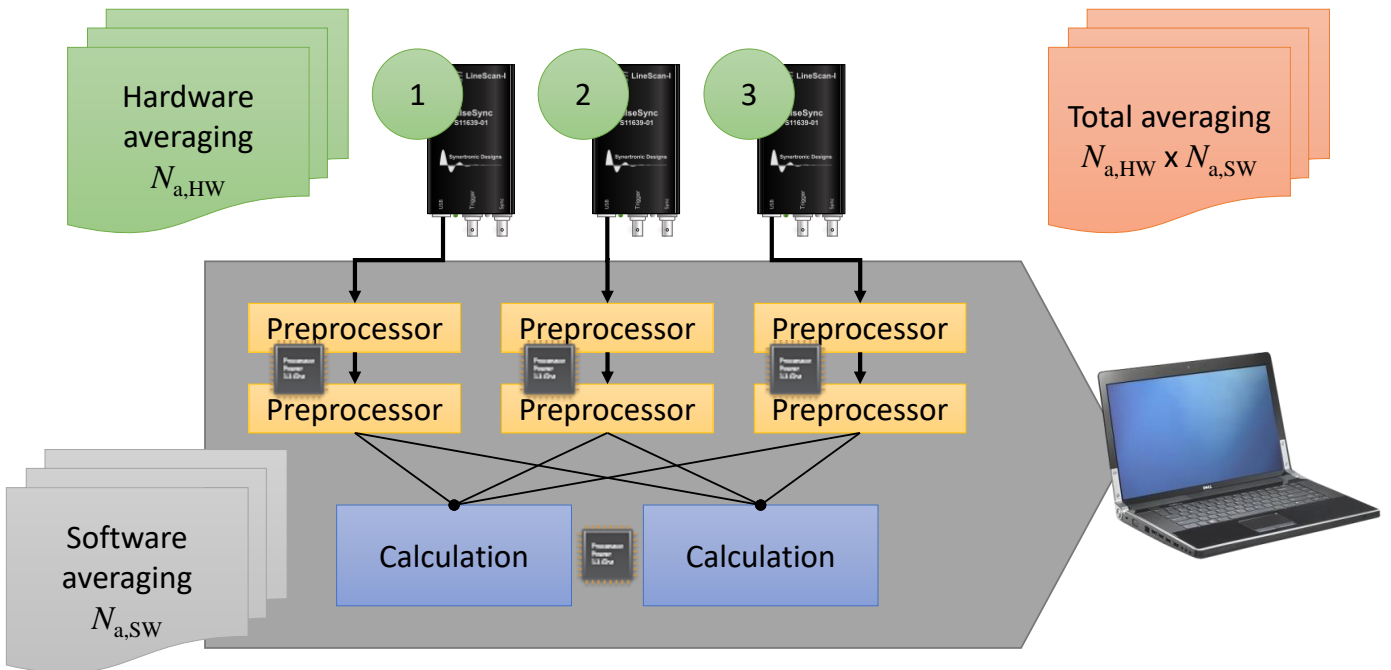

Figure 20 Measurement data flow.

Calculations are performed only when the pre-processed data from all the cameras for a given hardware averaged scan is available. The process of receiving averaged scans and performing pre-processing and calculations is performed $N_{a,SW}$ times. The results of the calculations are accumulated and at the end of the measurement the software average for each calculation is determined.

Scripting – Camera definitions

In order to use cameras, the must first be uniquely identified. Each camera has an entry in the script file using the following format[7]:

```
<camera serial="SN" number="NUM" [master="M"] [reverse="R"] [binning="B"]
        [gain="G"]/>
```

SN : The serial number of a camera is printed onto the back of the camera. The serial number has 13 digits and has the format: SYPB + device number + device version + instance number. For example: SYPB005010001. A serial number may only be defined once in a script file.

NUM : The camera number that will be assigned to the camera with the given serial number. This number will be used in the rest of the script file. This must be a unique number in the range [1 .. 1000].

M : Can be one of the following values: *0*, *1*, *true* or *false*. If the value is *1* or *true* the camera will be configured as the master camera. The master camera is the camera that must receive the trigger signal. Only one camera may be defined as the master. The default value is *0* or *false*.

R : Can be one of the following values: *0*, *1*, *true* or *false*. If the value is *1* or *true* the scan will be reversed and the data from pixels 0 to 1023 will be processed as pixels 1023 down to 0. The default value is *0* or *false*.

B : This value specifies the level of binning. It can be one of the following values:
   0   no binning (default)
   1   2-pixel binning
   2   4-pixel binning

G : Specifies the sensor gain. Provide one of the following string values:
   hi   High sensor gain
   lo   Low sensor gain
   This is only supported for the G11620 sensor. The gain setting will be ignored for all other sensors.

Scripting – Pre-processing steps

Each camera in the camera definition section may have its own set of pre-processing steps. The pre-processing steps are executed in the same order as defined in the script file. It is important to specify the pre-processing steps in the correct order. The following pre-processing steps are supported:

- Calibrate:
  Calibrates the scan data using the calibration stored on the corresponding camera.

- Inverse Fourier transform (IFFT):
  Calculates the inverse transform of a scan. It is assumed that a scan is performed with constant wavelength increments. The wavelength for each pixel is given by:

$$\lambda_n = \lambda_{\min} + \frac{\lambda_{\min} - \lambda_{\max}}{N-1} n \qquad \text{with} \qquad n = 0 .. 1023,$$

where *n* is the pixel number and $\lambda_{\min}$ and $\lambda_{\max}$ are the wavelength limits. The wavelength limits are specified outside the script file. In LabView a VI is provided to set the limits and in the stand-alone Glaz UI the limits can be specified on the user interface. The IFFT pre-processor will interpolate the

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[7] Parameters in square brackets […] are optional.

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scan in frequency space with constant increments. The IFFT is performed on the interpolated data.

It is possible to turn interpolation off, by setting the `interpolate` attribute to *false*. In this case, the IFFT is performed directly on the scan data.

- Background subtract:
  Before performing a measurement the background must be measured. In LabView a VI is provided and in the stand-alone Glaz UI an action can be triggered to take a background measurement. Note: The stored background will be the resulting data after pre-processing. The background subtraction must, therefore, always be the last pre-processing step.

A pre-processing step entry in the script file has the following format:

```
<preprocessor camera="NUM" type="T" [interpolate="I"]/>
```

NUM : The camera number that was assigned to a camera in the camera definition section. This pre-processing step will be applied to the scan data from the camera with the given number.

T : Can be one of the following values: *calibrate*, *ifft* or *background_subtract*.

I : This attribute is only applicable to the IFFT pre-processor. It can be one of the following values: *0*, *1*, *true* or *false*. If the value is *1* or *true*, the IFFT is performed on the interpolated data. If the value is *0* or *false*, no interpolation is done and the IFFT is performed directly on the scan data. The default value is *1* or *true*.

Scripting – Calculations

Any number of calculations in the calculations section can be defined. Calculations support operations on complex and real vectors. Complex vectors are supported, because the result from the IFFT pre-processor yields a complex vector. Each calculation uses a nested definition. The definition describes an expression tree (Wikipedia description). Below is an example of a calculation:

```
<calculation name="Example">
    <subtract>
        <divide>
            <measurement camera="1"/>
            <measurement camera="2"/>
        </divide>
        <divide>
            <measurement camera="3"/>
            <measurement camera="4"/>
        </divide>
    </subtract>
</calculation>
```

The equivalent equation for the above definition is:

$$\text{Example} = \frac{M_1}{M_2} - \frac{M_3}{M_4} \quad ,$$

where M_1, M_2, M_3 and M_4 are the pre-processed results from camera 1 to 4, respectively. In the example, the `subtract`, `divide` and `measurement` XML tags define the operations to be performed by the calculation. These tags are also called operators.

There are binary, unary and leaf operators. Binary operators require two child tags. In the example above, each `divide` operator has two `measurement` tags as children. A unary operator requires a single child tag. Leaf operators do not have child tags. Leaf operators are furthest to the right in the nested definition. In the above example, all `measurement` tags are leaf operators.

Table 10, Table 11 and Table 12 list the supported binary, unary and leaf operators, respectively.

Operation	Scalar-Scalar (s_1, s_2)	Scalar-Vector (s, v)	Vector-Vector (v_1, v_2)
Multiplication	$s_1 \cdot s_2$	$v_n \cdot s$ or $s \cdot v_n$, $n = 1..N$	$v_{1,n} \cdot v_{2,n}$, $n = 1..N$
Division	s_1/s_2	v_n/s, $n = 1..N$	$v_{1,n}/v_{2,n}$, $n = 1..N$
Addition	$s_1 + s_2$	$v_n + s$ or $s + v_n$, $n = 1..N$	$v_{1,n} + v_{2,n}$, $n = 1..N$
Subtraction	$s_1 - s_2$	$v_n - s$, $n = 1..N$	$v_{1,n} - v_{2,n}$, $n = 1..N$

Table 10 Binary operators.

Operation	Scalar (s)	Vector (v)
Magnitude	Not supported	$|v_n|$, $n = 0..N$
Phase	Not supported	$\widehat{v_n}$, $n = 0..N$

Table 11 Unary operators.

Operation	Result
Measurement	Returns the data of a given camera. The data is returned as a vector containing the 1024 values of the last pre-processed scan. If the IFFT pre-processor is used, the vector will contain complex values.
Scalar	Defines a single real, scalar value.

Table 12 Leaf operators.

Calculation definition start

A calculation and its definition starts with a calculation entry. A calculation entry in the script file has the following format:

```
<calculation [name="NAME"] [keepscans="K"]>
    … (operations)
</calculation>
```

NAME : The name of the calculation. In the Glaz UI this will be displayed in the legend of the measurement plot.

K : Can be one of the following values: *0, 1, true* or *false*. If the value is *1* or *true* each hardware averaged scan is saved and can be viewed in the Glaz UI. The default value is *0* or *false*.

The operations of a calculation are described by a nested definition using the operators summarised in Table 10, Table 11 and Table 12. See the sections below for more information on operators.

> ⚠ The calculation entry must only contain a single operator. This can either be a binary, unary or leaf operator.

After receiving the pre-processed data from each camera, the calculations are performed. The result of each calculation is accumulated and an average is calculated (see "Hardware and software averaging"). It is assumed, that the result is real. If the result contains complex values, the imaginary part will be ignored.

Binary operators

All binary operators have the following format:

```
<OP>
    <…>        (first child operator)
    <…>        (second child operator)
</OP>
```

OP : Can be one of the following values: *add*, *subtract*, *multiply* or *divide*.

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The function of the first and second child operators are described in the table below:

Operation	First child operator		Second child operator
Add	term 1	+	term 2
Subtract	minuend	-	subtrahend
Multiply	factor 1	·	factor 2
Divide	numerator	/	denominator

Table 13 Child tags of binary operators.

> ⚠ Division by zero is only handled gracefully for library versions 9.0 and higher. When a division-by-zero is encountered, the denominator is set to 2.22e-016 x signum(denominator). This prevents a division-by-zero error.

Unary operators

All unary operators have the following format:

```
<OP>
    <…>      (child operator)
</OP>
```

OP   :   Can be one of the following values: `magnitude` or `phase`.

The magnitude or phase is calculated from the data defined by the child operator.

The phase operator supports phase unwrapping. The algorithm for unwrapping the phase uses a threshold value. If the difference in phase between two successive data points is larger than the threshold value, then 2π will be added or subtracted from the next data point. The threshold value can be tweaked with the `threshold` attribute:

```
<phase [threshold="T"]>
```

T   :   A decimal number specifying the threshold as a faction of 2π. The default value is 0.75. For **T** > 1.0, phase unwrapping will be disabled.

Leaf operators

Tree leaf operators are supported: *scalar*, *measurement* and *reference*. The scalar operator has the following format:

```
<scalar value="V"/>
```

V   :   A decimal number. This is the return value of the scalar operator.

The measurement operator returns the pre-processed scan result of a camera. It has the following format:

```
<measurement camera="NUM" [ifft="IFFT"] [interpolate="I"]/>
```

NUM   :   The camera number that was assigned to a camera in the camera definition section. The operator will return the pre-processed data for the given camera.

IFFT :   Can be one of the following values: *0*, *1*, *true* or *false*. When not specified, the default value is *false*. If the value is *1* or *true* the operator will return the inverse Fourier transform (IFFT) of the pre-processed scan result. This function is useful when both IFFT and non-IFFT results are required. Note: this method is less efficient, than using the IFFT pre-processor.

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I : Can be one of the following values: *0, 1, true* or *false*. If the value is *1* or *true*, the IFFT is performed on the interpolated data. If the value is *0* or *false*, no interpolation is done and the IFFT is performed directly on the scan data. The default value is *1* or *true*.

The reference operator is used to access the result of another calculation. This is necessary when gated calculations need to be combined into a higher-level calculation. It has the following format:

```
<reference calculation="CALC"/>
```

CALC : The name of a previously defined calculation (see "Calculation definition start"). The operator will return result of the referenced calculation.

A calculation containing a measurement operator is also called a measurement calculation. A calculation containing a reference operator is also called a reference calculation.

⚠️ A calculation may not contain both a measurement and a reference operator. Reference calculations should only reference measurement calculations. Measurement calculations should be defined first, followed by any required reference calculations.

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PulseSync: Multi-camera configuration and synchronisation

The *PulseSync* mode was designed to support robust multi-camera operation. The design ensures that cameras remain synchronised and that they take scans at the same time. To achieve synchronisation, all the *Sync* ports of a multi-camera configuration must be connected together. Each camera is connected to a separate USB port on the PC or USB hub.
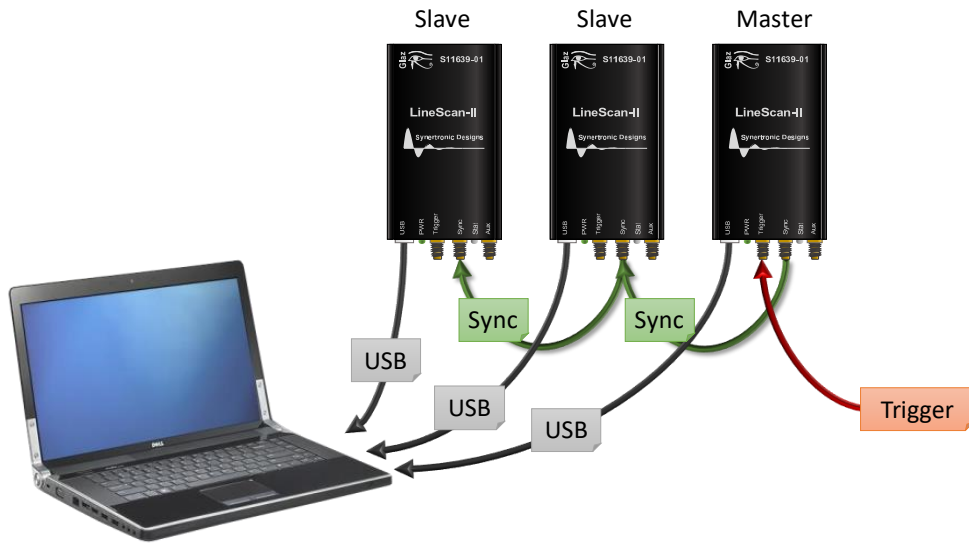
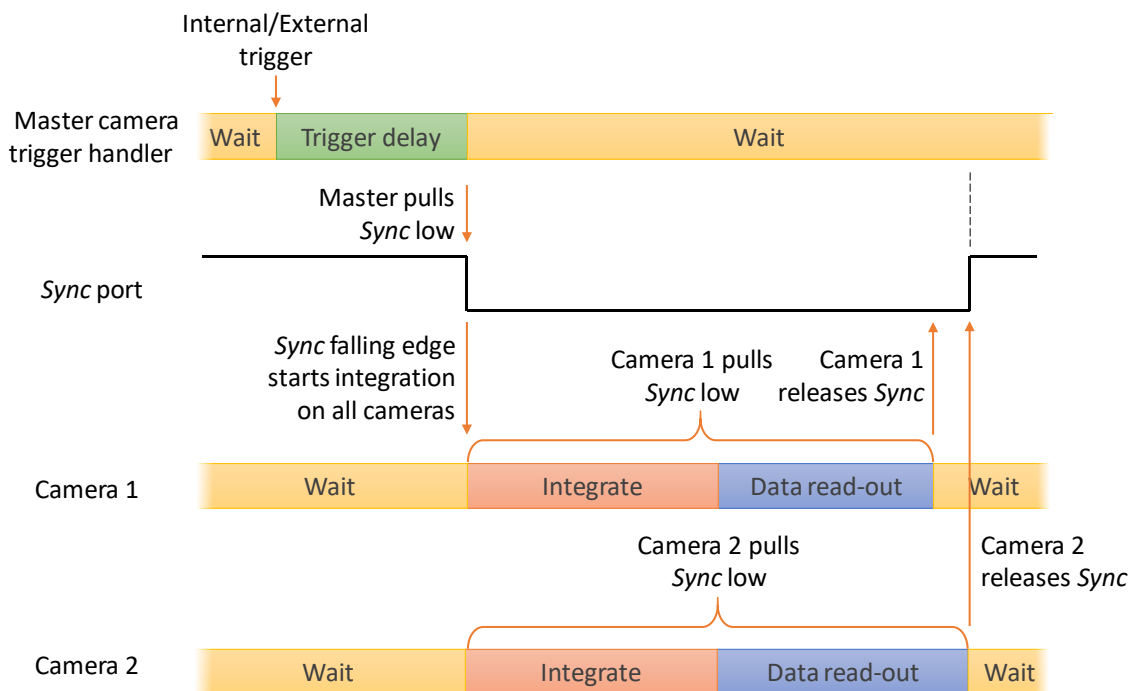**Figure 21** *PulseSync* multi-camera configuration with three cameras.

Figure 22 *PulseSync* synchronisation via the *Sync* port.

At least one camera must be defined as the *Master*. The *Master* receives the external trigger signal or generates the internal trigger signal. After the configured trigger delay, the *Master* pulls the *Sync* port low. This initiates the integration period on all connected cameras. Each camera pulls the *Sync* port low during the integration and data read-out period. The *Sync* port is released only after all the cameras have completed the data read-out. As long as any one of the cameras are busy with a scan or are sending data to a PC, the the *Sync* signal will remain asserted low.

⚠ If triggered internally, leave the *Trigger* port unconnected. The *Trigger* port of all slave cameras must be left unconnected.

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When a delayed trigger signal is received by the master camera, while the *Sync* signal is asserted, this trigger will be ignored. A multi-camera configuration will remain synchronised, even if the trigger frequency is higher than the processing speed of the cameras and PC. If the trigger frequency is higher than system's processing speed, some of the triggers will be ignored. Important to note, that all cameras will ignore the same trigger signal. It is safe to use a multi-camera configuration with USB 1.1 interfaces, USB 2.0 hubs or with slower PCs. The only side-effect will be a lower achievable scan rate and measurements can take longer.

PulseSync: Combining Glaz LineScan-II and Glaz-PD devices

It is possible to combine *Glaz LineScan-II* camera measurements with *Glaz-PD* devices. More information about *Glaz*-PD devices and its concepts can be found in the *Glaz-PD* manual.
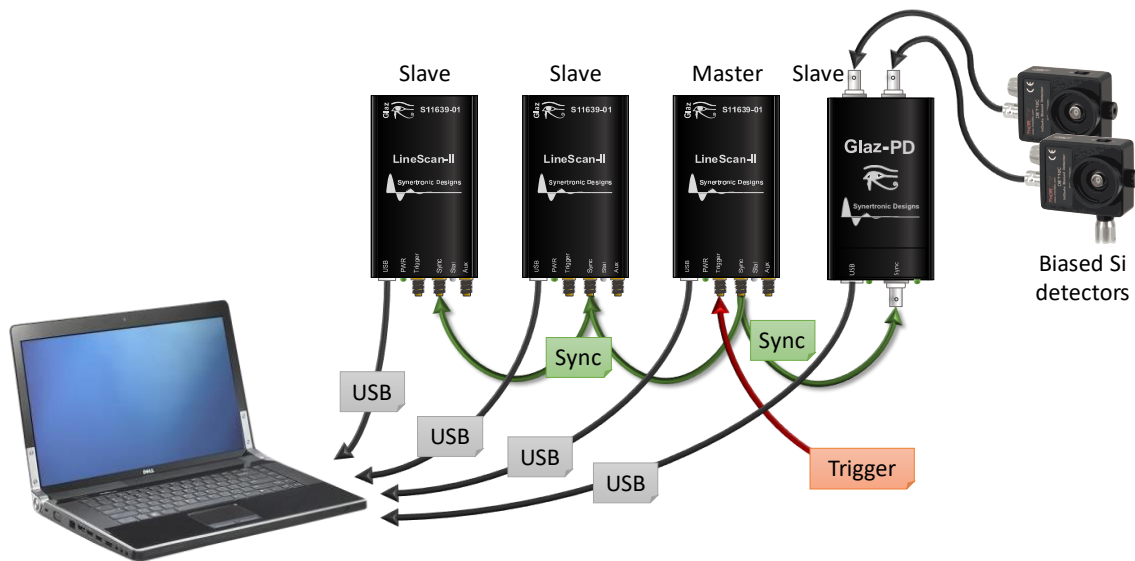

Figure 23 Combining *Glaz LineScan-II* cameras and *Glaz-PD*.

The following operations can be performed in conjunction with *Glaz-PD* devices:

- Normalisation of camera scans using measured laser pulse intensities from *Glaz-PD* devices.

- Gating of calculations based on "triggered" and "not triggered" states, detected by *Glaz-PD* devices.

In order to use measurements from *Glaz-PD* devices together with camera measurements, the *Glaz-PD* must be operated in synchronised mode. A typical connection diagram is shown in Figure 23.

Scripting – Glaz-PD definitions

In order to use *Glaz-PD* devices, the must first be uniquely identified. Each *Glaz-PD* has an entry in the script file as depicted in the example in Figure 24.

```
<!DOCTYPE GlazScript>
<config>
    <camera serial="SYBP005010001" number="1" master="1"/>      Camera definitions
    <pd serial ="SYBP006010001" number="1" ch1="1"/>            Glaz-PD definitions
    <preprocessor camera="1" type="calibrate"/>
    <preprocessor camera="1" type="subtract_background"/>       Pre-processing steps
    <calculation name="Camera 1" keepscans="1">
        <measurement camera="1"/>                               Calculations
    </calculation>
</config>
```

Figure 24 Defining *Glaz-PD* devices in the XML script file.

Each device definition uses the following format:

```
<pd serial="SN" number="NUM" [ch1="E1"] [ch2="E2"]
  [highgain2="G1"] [highgain1="G2"] [window="W"]/>
```

SN : The serial number of a device is printed onto the back of the camera. The serial number has 13 digits and has the format: SYPB + device number + device version + instance number. For example: SYPB006010001. A serial number may only be defined once in a script file.

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NUM	:	The device number that will be assigned to the *Glaz-PD* device with the given serial number. This number will be used in the rest of the script file. This must be a unique number in the range [1 .. 1000].
E1,E2	:	Can be one of the following values: *0*, *1*, *true* or *false*. If the value is *1* or *true* the given channel will be enabled. The default value is *0* or *false* and when omitted the relevant channel will be disabled.
G1,G2	:	Can be one of the following values: *0*, *1*, *true* or *false*. If the value is *1* or *true* the high-gain stage (x6 gain) for the given channel will be enabled. The default value is *0* or *false* and when omitted the relevant high-gain stage will be disabled.
W	:	This specifies the window period in [μs]. The default value is 10 μs.

Scripting - Normalising camera scans

Calculations can be normalised using one of two methods.

A camera measurement may be directly normalised by adding an additional parameter to the camera measurement leaf operator (see "Leaf operators"):

```
<measurement camera="NUM" pdnorm="PD_LIST"/>
```

NUM	:	The camera number that was assigned to a camera in the camera definition section. The operator will return the pre-processed data for the given camera.
PD_LIST	:	This is a comma-separated list of *Glaz-PD* device numbers and channel numbers. Each entry in the list uses the following format: **PD_NUM:PD_CH** For example: pdnorm="1:1,1:2". This will use channel 1 and 2 of the *Glaz-PD* device with the device number "1" to normalise the camera scan. The resulting normalisation factor for the ith scan will be:

$$\frac{I_{1:1,0}}{I_{1:1,i}} \cdot \frac{I_{1:2,0}}{I_{1:2,i}}$$

A calculation can also be normalised at a higher level by adding a unary normalisation operator. The operator has the following format:

```
<normalise pdnorm="PD_LIST">
     <…>    (child operator)
</normalise>
```

PD_LIST	:	This is a comma-separated list of *Glaz-PD* device numbers and channel numbers. Each entry in the list uses the following format: **PD_NUM:PD_CH** For example: pdnorm="1:1,1:2". This will use channel 1 and 2 of the *Glaz-PD* device with the device number "1" to normalise the camera scan. The resulting normalisation factor for the ith scan will be:

$$\frac{I_{1:1,0}}{I_{1:1,i}} \cdot \frac{I_{1:2,0}}{I_{1:2,i}}$$

Scripting - Gating calculations

It is possible to "gate" calculations. This makes it possible to perform defined calculations only if the associated *Glaz-PD* channel was either triggered or not triggered. In order to gate a calculation additional parameters must be specified in the calculation start definition (see "Calculation definition start"):

```
<calculation [name="NAME"] [keepscans="K"] pdgate="PD" gatestate="S">
     … (operations)
</calculation>
```

NAME	:	The name of the calculation. In the Glaz UI this will be displayed in the legend of the measurement plot.

K : Can be one of the following values: *0*, *1*, *true* or *false*. If the value is *1* or *true* each hardware averaged scan is saved and can be viewed in the Glaz UI. The default value is *0* or *false*.

PD : This is only one entry, instead of a list, defining the *Glaz-PD* device number and channel number. The entry uses the following format: **PD_NUM:PD_CH**
For example: pdgate="1:2". This will use channel 2 of the *Glaz-PD* device with the device number "1".

S : Can be one of the following values: *0*, *1*, *true* or *false*. If the value is *1* or *true* the calculation will be performed and accumulated only when the associated Glaz-PD channel was triggered. If the value is *0* or *false* the calculation will be performed and accumulated only when the associated Glaz-PD channel was <u>not</u> triggered.

> ℹ When keepscans is enabled for a gated calculation all scans are kept, even scans for which the calculation was not performed. When a calculation is not performed due to gating, that kept scan will be all zeros.

Error detection

A measurement will be terminated if a digitized value from a *Glaz-PD* was expected, but that channel was not triggered. This will happen if a camera scan needs to be normalised, but the channel used for the normalisation was not triggered during the specified *Glaz-PD* window period.

TimeFill: Multi-camera configuration and synchronisation

TimeFill mode can be used were multi-camera measurements with large temporal fill factors are required. Multi-camera synchronisation in *TimeFill* mode is not as robust as in *PulseSync* mode and the following guidelines must be followed:

- The integration period must be at least 20 μs shorter than the repetition period. For example:
  Line rate = 1000 lines/s $\rightarrow$ repetition period = 1 ms $\rightarrow$ maximum integration period = 980 μs
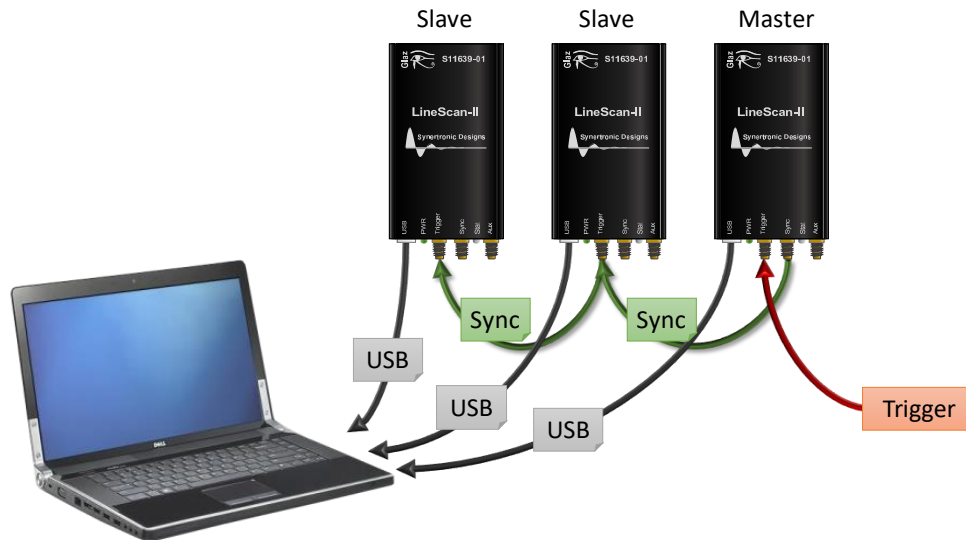- Limit the number of scans per measurement to prevent FIFO buffer overruns.

Figure 25 *TimeFill* multi-camera configuration with three cameras.

The cameras must be configured as follows:

1. At least one camera must be defined as the *Master*. The *Master* receives the external trigger signal or generates the internal trigger signal.

2. Configure the *Sync* port of the *Master*:
   IO port function = *Integration window*
   Active low = *false*

3. Connect the *Trigger* port of each *Slave* to the *Sync* port of the *Master*.

4. Configure the trigger mode and trigger delay of each Slave:
   Trigger mode = *External trigger*
   Trigger delay = 0 μs

   > ⚠ If the *Master* is triggered internally, leave the *Trigger* port unconnected.

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Examples

In order to get a better understanding of how to compile script files a few examples are presented. The *Glaz UI* installation contains an example script file for each example discussed below.

The following symbols are used:

- S_n The measured spectrum from the nth camera.

- B_n The measured background for the nth camera.

- I_m The intensity measured by a *Glaz-PD* device.

- F_k Functions that need to be calculated.

In each example, a function is presented. The way to compile a script file to calculate this function is shown and how function is mapped onto the script. Mappings are indicated by coloured boxes: Boxes with the same colour in the script and on the function show the equivalent mapping.

All calculations performed by the script are averaged over the specified number of scans (see "Hardware and software averaging").

> ⚠ The serial numbers used in the example scripts are for illustration only. In a practical set-up, the actual camera serial numbers must be used.

Example 1 – Single camera measurement

$$F_1 = S_1\text{-}B_1$$

The function simply takes scans with a single camera and subtracts the initially measured background. The script is written as follows:

```
<!DOCTYPE GlazScript>
<config>
    <camera serial="SYBP005010001" number="1" master="1"/>
    <preprocessor camera="1" type="subtract background"/>
    <calculation name="F1">
        <measurement camera="1"/>
    </calculation>
</config>
```

The function is mapped as follows:

$$F_1 = S_1\text{-}B_1$$

The blue box represents the pre-processor step in the script. This step already subtracts the background from each camera measurement. The calculation simply returns the camera measurement, which includes the background subtraction.

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Example 2 – Ratio of two camera measurements

$$F_2 = \frac{S_1\text{-}B_1}{S_2\text{-}B_2}\text{-}1$$

The function simply takes scans from two cameras and subtracts the initially measured backgrounds from each scan. The ratio of the scans (with subtracted backgrounds are then taken). The script is written as follows:

```
<!DOCTYPE GlazScript>
<config>
    <camera serial="SYBP005010001" number="1" master="1"/>
    <camera serial="SYBP005010002" number="2" master="0"/>
    <preprocessor camera="1" type="subtract_background"/>
    <preprocessor camera="2" type="subtract_background"/>
    <calculation name="F2">
        <subtract>
            <divide>
                <measurement camera="1"/>
                <measurement camera="2"/>
            </divide>
            <scalar value="1"/>
        <subtract>
    </calculation>
</config>
```

The function is mapped as follows:

$$F_2 = \frac{S_1\text{-}B_1}{S_2\text{-}B_2}\text{-}1$$

The blue and red boxes represent the pre-processor steps in the script. These steps already subtract the backgrounds from each camera measurement. The calculation divides the measurements from camera 1 with the measurements from camera 2 and subtracts the value of 1. The measurements (green and yellow boxes) already include the background subtraction.

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Example 3 – Normalised ratio of two camera measurements

$$F_3 = \frac{I_{1,0}}{I_1} \left(\frac{S_1 - B_1}{S_2 - B_2} - 1 \right)$$

The function is the same as in Example 2, except the result is also normalised with respect to the first measured intensity $I_{1,0}$ (see "Scripting - Normalising camera scans" for more information). The script is written as follows:

```
<!DOCTYPE GlazScript>
<config>
    <camera serial="SYBP005010001" number="1" master="1"/>
    <camera serial="SYBP005010002" number="2" master="0"/>
    <pd serial="SYBP006010001" number="1" ch1="1" ch2="0"/>
    <preprocessor camera="1" type="subtract_background"/>
    <preprocessor camera="2" type="subtract_background"/>
    <calculation name="F3">
        <normalise pdnorm="1:1">
            <subtract>
                <divide>
                    <measurement camera="1"/>
                    <measurement camera="2"/>
                </divide>
                <scalar value="1"/>
            </subtract>
        </normalise>
    </calculation>
</config>
```

The function is mapped as follows:

$$F_3 = \frac{I_{1,0}}{I_1} \left(\frac{S_1 - B_1}{S_2 - B_2} - 1 \right)$$

The grey box represents the same calculation as in Example 2. The red box represents the normalisation. In this example the normalisation is performed using channel 1 of *Glaz-PD* device number 1 (`pdnorm="1:1"`). The measurement of the initial intensity $I_{1,0}$ and calculation of the ratio $I_{1,0}/I_1$ is performed automatically.

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Example 4 – Gated (even/odd) measurements with two cameras

$$F_4 = \frac{I_{2,0}}{I_{2,even}} \cdot \frac{I_{1,0}}{I_{1,even}} \left(\frac{S_{1,even}-B_1}{S_{2,even}-B_2} - 1 \right) - \frac{I_{2,0}}{I_{2,odd}} \left(\frac{S_{1,odd}-B_1}{S_{2,odd}-B_2} - 1 \right)$$

In transient absorption spectroscopy (TAS) a pump-probe approach is used. The target illumination alternates between probe-only and pump-probe. The alternating illumination states are also called even/odd states. The *Glaz-PD* device is used to differentiate between these two states. Calculations are then gated based on the *Glaz-PD* states. The script is written as follows:

```
<!DOCTYPE GlazScript>
<config>
    <camera serial="SYBP005010001" number="1" master="1"/>
    <camera serial="SYBP005010002" number="2" master="0"/>
    <pd serial="SYBP006010001" number="1" ch1="1" ch2="1"/>
    <preprocessor camera="1" type="subtract_background"/>
    <preprocessor camera="2" type="subtract_background"/>
    <calculation name="Even" pdgate="1:1" gatestate="1">
        <normalise pdnorm="1:1,1:2">
            <subtract>
                <divide>
                    <measurement camera="1"/>
                    <measurement camera="2"/>
                </divide>
                <scalar value="1"/>
            </subtract>
        </normalise>
    </calculation>
    <calculation name="Odd" pdgate="1:1" gatestate="0">
        <normalise pdnorm="1:2">
            <subtract>
                <divide>
                    <measurement camera="1"/>
                    <measurement camera="2"/>
                </divide>
                <scalar value="1"/>
            </subtract>
        </normalise>
    </calculation>
    <calculation name="F4">
        <subtract>
            <reference calculation="Even"/>
            <reference calculation="Odd"/>
        </subtract>
    </calculation>
</config>
```

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The function is mapped as follows:

$$F_4 = \frac{I_{2,0}}{I_{2,even}} \cdot \frac{I_{1,0}}{I_{1,even}}\left(\frac{S_{1,even}\text{-}B_1}{S_{2,even}\text{-}B_2}\text{-}1\right) - \frac{I_{2,0}}{I_{2,odd}}\left(\frac{S_{1,odd}\text{-}B_1}{S_{2,odd}\text{-}B_2}\text{-}1\right)$$

Even term · Odd term

The yellow and green boxes each represent the same calculation as in Example 3. Except, the even term (yellow box) uses two normalisation factors. In this example channel 1 of the *Glaz-PD* device number 1 is used to perform the gating function. When a scan is triggered and *Glaz-PD* channel 1 is <u>also</u> triggered, then the even term will be calculated. When a scan is triggered and *Glaz-PD* channel 1 is <u>not</u> triggered, then the odd term will be calculated (see "Scripting - Gating calculations" for more information). Since gating can only be applied to calculations, the complete function F_4 cannot be represented by a single calculation in the script file. A third calculation needs to be defined. This calculation subtracts the odd term from the even term. This is a reference calculation and it references the "Even" calculation (yellow boxes) and "Odd" calculation (green boxes). The reference calculation is performed each time an "Odd" and "Even" calculation result is available. This happens only with every second scan.

The result for 10 scans could look as follows:

Scan	Glaz-PD channel 1 triggered?	"Odd" Calculated?	Kept scan result	"Even" Calculated?	Kept scan result	"F4" Calculated?	Kept scan result
1	✗	✓	✓	✗	All zeros	✗	All zeros
2	✓	✗	All zeros	✓	✓	✓	✓
3	✗	✓	✓	✗	All zeros	✗	All zeros
4	✓	✗	All zeros	✓	✓	✓	✓
5	✗	✓	✓	✗	All zeros	✗	All zeros
6	✓	✗	All zeros	✓	✓	✓	✓
7	✗	✓	✓	✗	All zeros	✗	All zeros
8	✓	✗	All zeros	✓	✓	✓	✓
9	✗	✓	✓	✗	All zeros	✗	All zeros
10	✓	✗	All zeros	✓	✓	✓	✓
Average		2,4,6,8,10		1,3,5,7,9		1,3,5,7,9	

The ✓ and ✗ indicate whether a calculation is performed or not. In addition, the result for kept scans (when `keepscans="1"`) is also indicated. In the bottom row the scan numbers used to calculate the averages is shown.

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