

Basler ToF Camera



USER'S MANUAL

Document Number: AW001338

Version: 10 Language: 000 (English)

Release Date: 9 April 2018

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1 General Information

The purpose of this document is to familiarize you with the basic capabilities of the Basler ToF Camera. This document provides important information about the camera's features, safe use of the camera, and installation procedures.

1.1 Terms of Use

Basler offers a 1-year-warranty for this camera.

Warranty Information

To ensure that your warranty remains in force, adhere to the following guidelines:

Do not remove the camera's serial number label

If the label is removed and the serial number can't be read from the camera's registers, the warranty is void.

Do not open the camera housing

Do not open the housing. Touching internal components may damage them.

Prevent ingress or insertion of foreign substances into the camera housing

Prevent liquid, flammable, or metallic substances from entering the camera housing. If operated with any foreign substances inside, the camera may fail or cause a fire.

Avoid electromagnetic fields

Do not operate the camera in the vicinity of strong electromagnetic fields. Avoid electrostatic charging.

Transport in original packaging

Transport and store the camera in its original packaging only. Do not discard the packaging.

Clean with care

If you have to clean the housing of the camera, follow the guidelines in the notice on [page 4](#).

Read the manual

Read the manual carefully before using the camera.

2 Precautions

2.1 Safe Usage of the Camera



DANGER

Electric Shock Hazard

Non-approved power supplies may cause electric shock. Serious injury or death may occur.

You must use a camera power supply that meets the Safety Extra Low Voltage (SELV) and Limited Power Supply (LPS) requirements.



WARNING

Fire Hazard

Non-approved power supplies may cause fire and burns.

You must use a camera power supply that meets the Limited Power Supply (LPS) requirements.



CAUTION

Invisible Radiation

This camera is equipped with LEDs that emit invisible near-infrared light which may be harmful to the eye. The LEDs are classified as risk group 1 (low risk) according to EN 62471:2008 which means that the product presents no risk related to exposure limits under normal usage conditions. At distances above 25 cm or exposure times under 750 s, the LEDs fall into risk group 0 (no risk). For more information, see the Appendix on page [75](#).

However, eye safety can only be guaranteed if the camera is operated within the specifications set out in this document.

This classification is valid when using a single product only and does not account for exposure from multiple sources.

Documentation

The Basler ToF Camera documentation (this manual and the *Basler ToF Camera Getting Started Guide*) must be available to all staff working with the Basler ToF Camera. All safety notices contained in the documentation must be observed.

2.2 Power

NOTICE

Using an incorrect power supply can damage the camera.

If you are supplying camera power via the camera's 12-pin connector and the voltage is greater than 24 VDC ($\pm 10\%$), the camera may get damaged. If the voltage is lower than that, the camera may not work as expected and you may not be able to acquire images.

Only use a power supply with a maximum output current of 2 A.

NOTICE

Incorrect plugging in and unplugging of the camera's power cable can damage the camera.

To avoid switch-on surges damaging the camera, only plug in the power cable into the camera's 12-pin connector or unplug it from the connector if the power supply is switched off.

2.3 Temperature

NOTICE

Extreme temperatures can damage the camera.

To avoid damaging the camera and to achieve optimum performance, observe the maximum and minimum housing temperatures set out in Section 3.7.1 on [page 11](#).

2.4 Handling and Cleaning

NOTICE

Handling of the Camera

- Don't try to alter the position of the lens.
Each camera is geometrically calibrated at the factory to enable the camera to achieve precise measurements. As a result, the lens is fixed on the camera at a specific distance from the sensor and secured. Trying to alter the position of the lens in any way will result in this calibration being lost and will lead to incorrect measurements.
- Don't open the camera housing. Touching internal components may damage them.
- If the camera is not in use, store it in its original packaging.

NOTICE

Cleaning of the Camera Housing

To clean the surface of the camera housing:

- Do not use solvents or thinners; they can damage the surface.
- Use a soft, dry cloth that won't generate static during cleaning (cotton is a good choice).
- To remove tough stains, use a soft cloth dampened with a small amount of neutral detergent; then wipe dry.
- Make sure that the detergent has evaporated after cleaning, before reconnecting the camera to power.

3 Specifications and Requirements

3.1 General Specifications

Specification	Basler ToF Camera
Resolution (H x V pixels)	640 x 480
Sensor Type	Panasonic MN34902BL
Optical Size	1/4"
Lens	3.6 mm
Field of View (H x V)	57° x 43°
Max. Frame Rate (at full resolution in Standard processing mode)	20 fps
Mono/Color	Mono
Wavelength	850 nm, ±30 nm
Non-ambiguity Range	0–13.320 m (default channel)
Absolute Accuracy and Repeatability	Absolute Accuracy: ±1 cm * Repeatability (1 σ): 8 mm *
Drift with Temperature	0.7 mm/K For detailed information, see Section 6.2.3 on page 36 .
External Light Disturbance	above 15 kLux
Communication Interface	Gigabit Ethernet (1000 Mbit/s)
Image Components	<ul style="list-style-type: none"> ■ Range map ■ Intensity image ■ Confidence map

Table 1: General Specifications (tof640-20gm)

Specification	Basler ToF Camera
Pixel Formats	<ul style="list-style-type: none"> ■ Coord3D_C16 Available for the range map ■ Mono16 Available for the intensity image ■ Confidence16 Available for the confidence map ■ RGB8 Available for the range map ■ Coord3D_ABC32f (point cloud) Available for the range map
Synchronization	Free run, via hardware or software trigger
Exposure Time Control	Programmable via the camera API, Auto Mode
Camera Power Requirements	24 VDC ($\pm 10\%$), supplied via the camera's 12-pin connector
Max Power Consumption	15 W avg 29 W peak (1.2 A @ 24 VDC)
Cooling	Passive, no fan
Enclosure Rating	IP30
Size (L x W x H)	141.9 mm x 61.5mm x 76.4 mm
Weight	≈ 450 g
Lens Adapter	n/a (Integrated lens)
Multi-Camera Setup	Via Multichannel feature or trigger synchronization
Conformity	CE (includes RoHS), GenICam, GigE Vision, FCC The EU Declaration of Conformity is available on the Basler website: www.baslerweb.com
Eye Safety	EN 62471:2008 RG 1
Software	Basler ToF Driver (version 1.1.0 or higher) Available for Windows (x86, x64) and Linux (x86, x64)

Table 1: General Specifications (tof640-20gm)

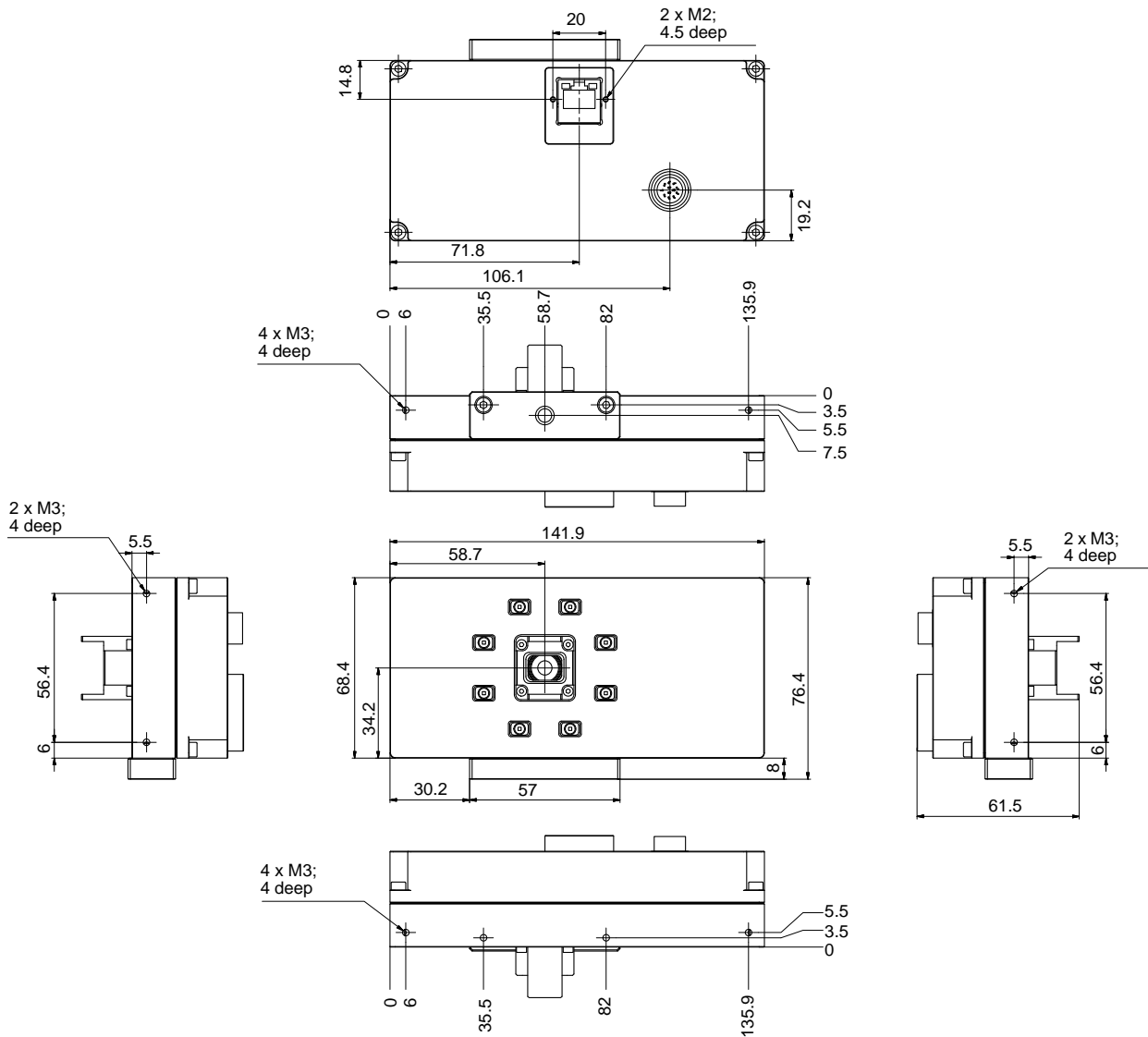
* Measured under the following conditions:

- camera model 107002-07 with default settings
- default channel
- 20 minutes camera warm-up time
- sheet of white paper as target object
- no ambient light
- 22 °C room temperature
- 40 x 40 pixels in the center of the range map
- 25 images
- offset corrected

For more information about accuracy and repeatability, see Section 6.1.1 on [page 33](#).

3.2 Mechanical Specifications

This section contains information about the dimensions and mounting points of the Basler ToF Camera.



Dimensions in mm

Fig. 1: Camera Dimensions

3.3 Coordinate System of the Camera

The Basler ToF Camera uses a right-handed coordinate system with the y axis pointing down (see Figure 2).

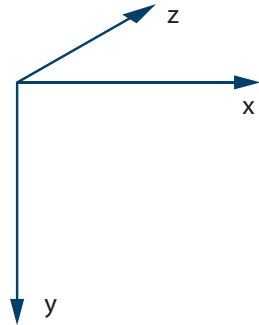


Fig. 2: Coordinate System Viewed from the Perspective of the Camera

Origin of the Coordinate System

The origin of the coordinate system is defined by the following positions:

- the **X** and **Y** coordinates are 0 (zero) at the pixel at the center of the sensor
- the **Z** coordinate is 0 (zero) at the front of the camera housing

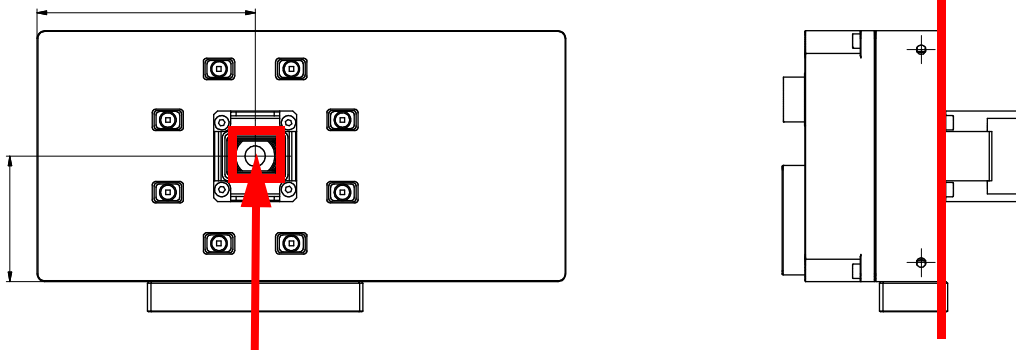


Fig. 3: Origin of the Coordinate System



Many common point cloud processing tools, e.g., MeshLab and CloudCompare, also use right-handed coordinate systems, but with the y axis pointing up. Because of this difference in the orientation of the y axis, these tools show point clouds produced by the Basler ToF Camera backwards and upside down.

To make the point clouds compatible with these tools, they need to be rotated along the x axis by 180 °. This is equivalent to multiplying the y and z values by -1. This is illustrated in the Save Point Cloud sample that is included in the Basler ToF Driver package.

Alternatively, you can use the **Save Depth and Image Data** feature of the ToF Viewer which allows you to have this rotation done automatically when saving a point cloud to file. By selecting the **Invert z-axis** checkbox (enabled by default), the point clouds will be made compatible with the aforementioned tools.

For more information about the **Save Depth and Image Data** feature, see "Saving Depth and Image Data" on [page 54](#) or the **Saving Depth and Image Data** topic in the ToF Viewer online help.

3.4 Hardware Requirements

- Basler ToF Camera
- Power supply
- GigE cable
- Camera bracket
- Computer with the following specifications:
 - Processor: Intel i5 2.4 GHz or better
 - RAM: 4 GB minimum
 - Network adapter: Intel Pro 1000 (recommended)

3.5 Software Requirements

- Operating system
 - 32-bit Windows 7
 - 64-bit Windows 7 (recommended)
 - Linux (x86, x64)

- Basler ToF Driver

The Basler ToF Driver software is available for Windows and Linux operating systems and includes the following:

- ToF Viewer (Windows only)
- pylon Viewer (ToF); (Linux only)
- ToF IP Configurator
- GenICam GenTL producer
- Sample code

You can download the Basler ToF Driver from the Basler website: www.baslerweb.com/tof. Go to the **Downloads** tab and choose the required version.

3.6 Electrical Requirements

Power must be supplied to the camera via the 12-pin connector. For information about the connector pin assignments, see Table 3 on [page 16](#).

Voltage Requirements	Max Power Consumption
24 VDC ($\pm 10\%$)	15 W avg 29 W peak (1.2 A @ 24 VDC)

Table 2: Camera Power

NOTICE

Using an incorrect power supply can damage the camera.

If you are supplying camera power via the camera's 12-pin connector and the voltage is greater than 24 VDC ($\pm 10\%$), the camera may get damaged. If the voltage is lower than that, the camera may not work as expected and you may not be able to acquire images.

Only use a power supply with a maximum output current of 2 A.

NOTICE

Incorrect plugging in and unplugging of the camera's power cable can damage the camera.

To avoid switch-on surges damaging the camera, only plug in the power cable into the camera's 12-pin connector or unplug it from the connector if the power supply is switched off.

3.7 Environmental Requirements

3.7.1 Temperature and Humidity

Housing temperature during operation:	0–50 °C (32–122 °F)
Humidity during operation:	20–80 %, relative, non-condensing
Storage temperature:	-20–80 °C (-4–176 °F)
Storage humidity:	20–80 %, relative, non-condensing



Influence of Temperature on Camera Performance

Temperature has a significant impact on the performance of the camera. For more information, see Section 6.2.3 on [page 36](#).

3.7.2 Heat Dissipation

You must provide sufficient heat dissipation to maintain a stable camera housing temperature. Since each installation is unique, Basler only provides the following general guidelines:

- In all cases, you should monitor the temperature of the camera housing and make sure that the temperature doesn't exceed 50 °C.
- Provide sufficient heat dissipation. Consider one of the following options:
 - Mounting the camera on a substantial, thermally conductive component that can act as a heat sink.
 - Using a fan to provide an air flow over the camera.

3.7.3 Automatic Temperature Control

The Basler ToF Camera is equipped with two temperature sensors that measure the temperature of the LED board and the sensor board respectively.

If temperatures at which reliable operation of the camera can't be guaranteed anymore are reached, the image acquisition will be switched off and the camera will send a test image. If this happens, try to reduce the temperature of the camera by lowering the exposure time or the frame rate or by providing more heat dissipation (see [Section 3.7.2](#)).

When the temperatures have fallen by approx. 10 %, LED and sensor board will come back on and image acquisition will be resumed.

Temperatures at which the image acquisition will be switched off:

- Sensor board: 75 °C
- LED board: 66 °C

3.8 Software Licensing Information

3.8.1 LWIP TCP/IP Licensing

The software in the camera includes the LWIP TCP/IP implementation. The copyright information for this implementation is as follows:

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3.8.2 LZ4 Licensing

The software in the camera includes the LZ4 implementation. The copyright information for this implementation is as follows:

LZ4 - Fast LZ compression algorithm

Copyright (C) 2011-2013, Yann Collet.

BSD 2-Clause License (<http://www.opensource.org/licenses/bsd-license.php>)

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3.8.3 Basler ToF Driver Third-Party Licenses

The Basler ToF Driver package makes use of several libraries put under different open source licenses. Refer to the Third-Party_Licenses.html document included in the Basler ToF Driver package for a list of third-party libraries and the respective licenses texts.

4 Physical Interface

4.1 Camera Connectors

The Basler ToF Camera is equipped with two connectors at the back of its housing as shown in [Figure 4](#):

- 12-pin connector
- 8-pin RJ45 jack

For more information about pin assignments and connector types, see the following sections.

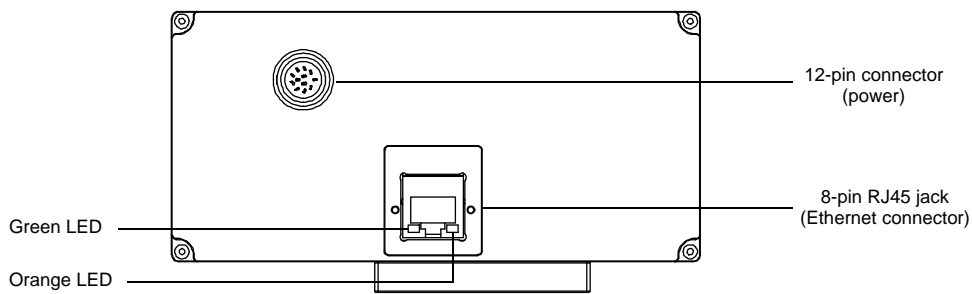


Fig. 4: Camera Connectors

4.1.1 12-pin Connector

The 12-pin connector is used to access the two physical input lines and two physical output lines available in the camera. The pin assignments and pin numbering for the receptacle are as shown in [Table 3](#).

The 12-pin connector of the camera is a Hirose micro receptacle (part number HR10A-10R-12P) or the equivalent.

The recommended mating connector is the Hirose micro plug (part number HR10A-10P-12S) or the equivalent.

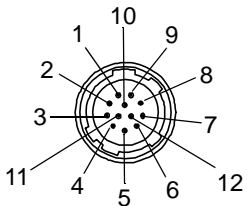

	Pin	Function	Pin	Function
		1	Camera Power Ground *	7
	2	Camera Power Ground *	8	Camera Power VCC **
	3	Opto In 1	9	Camera Power VCC **
	4	Opto In 2	10	Opto Out VCC
	5	Opto In Ground	11	n/a
	6	Opto Out 1	12	n/a
			Shield	Shield Ground / PE *** *** Shield Ground is AC-coupled to pins 1 and 2 inside the camera.

Table 3: Connector Pin Assignments and Numbering

	<p>* Pins 1 and 2 are tied together inside the camera.</p> <p>** Pins 8 and 9 are tied together inside the camera.</p> <p>To avoid a voltage drop when there are long wires between the power supply and the camera, Basler recommends that you provide 24 VDC camera power through two separate wires between the power supply and pins 8 and 9. Basler also recommends that you provide camera power ground through two separate wires between the power supply and pins 1 and 2.</p>
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NOTICE

An incorrect plug can damage the 12-pin connector.

The plug on the cable that you attach to the camera's 12-pin connector must have 12 female pins. Using a plug with a smaller or larger number of pins can damage the connector.

4.1.2 8-pin RJ45 Jack

The 8-pin RJ45 jack provides Ethernet access to the camera. Pin assignments are as specified in the Ethernet standard. It is a standard RJ45 connector.

The recommended mating connector is any standard 8-pin RJ45 plug. Cables terminated with screw-lock connectors are available from Basler. Visit www.baslerweb.com to order or contact your Basler sales representative.

When ordering cables with screw lock, respect the horizontal orientation of the screws.

4.2 Camera Cabling Requirements

4.2.1 Ethernet Cables

Use high-quality Ethernet cables. To avoid EMI, the cables must be shielded. Use of category 6 or category 7 cables with S/STP shielding is strongly recommended. As a general rule, applications with longer cables or applications in harsh EMI conditions require higher category cables.

Either a straight-through (patch) or a cross-over Ethernet cable can be used to connect the camera directly to a GigE network adapter in a computer or to a GigE network switch.

Close proximity to strong magnetic fields should be avoided.

4.2.2 Power and I/O Cable

A single power and I/O cable is used to supply power to the camera and to connect to the camera's I/O lines as shown in [Figure 5](#).

The end of the power and I/O cable that connects to the camera must be terminated with a Hirose micro plug (part number HR10A-10P-12S) or the equivalent. The cable must be wired to conform with the pin assignments shown in the pin assignment table (see [Table 3](#) on [page 16](#)).

The maximum length of the power and I/O cable is 10 meters. The cable must be shielded.

Close proximity to strong magnetic fields should be avoided.

The required 12-pin Hirose plug is available from Basler. Basler also offers cable assemblies that are terminated with a 12-pin Hirose plug on one end and unterminated on the other. Visit www.baslerweb.com to order or contact your Basler sales representative.

NOTICE

An incorrect plug can damage the 12-pin connector.

The plug on the cable that you attach to the camera's 12-pin connector must have 12 female pins. Using a plug with a smaller or larger number of pins can damage the connector.

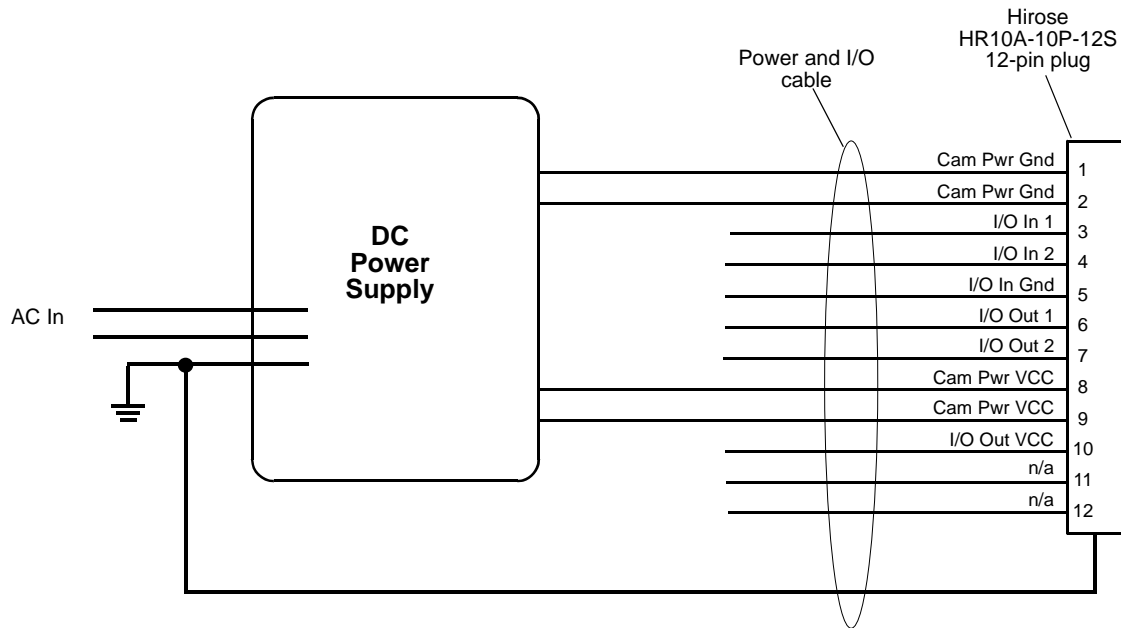



Fig. 5: Power and I/O Cable

	<p>To avoid a voltage drop with long power wires, Basler recommends that you supply camera power VCC through two separate wires between the power supply and the camera as shown in the figure above.</p> <p>It's also recommended that you supply camera power ground through two separate wires between the power supply and the camera as shown in the figure.</p>
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For more information about applicable voltage levels, see Section 4.4.1 on [page 21](#).

4.3 Input Line Description

4.3.1 Voltage Requirements

Voltage Levels When Power and I/O Cable is Used

When a power and I/O cable is used, the following voltage requirements apply to the camera's I/O input lines (pins 3 and 4 of the 12-pin connector):

Voltage	Description
0–24 VDC	Operating voltage.
0–1.4 VDC	The voltage indicates a logical 0.
>1.4–2.2 VDC	Region where the logic level transition occurs; the logical state is not defined in this region.
>2.2 VDC	The voltage indicates a logical 1.

Table 4: Voltage Requirements for the I/O Inputs When Using a Power and I/O Cable

4.3.2 Characteristics

The camera is equipped with two physical input lines designated as input line 1 and input line 2. The input lines are accessed via the 12-pin connector at the back of the camera.

As shown in the I/O line schematic, each input line is opto-isolated. See Section 4.3.1 on [page 19](#) for recommended input voltages and their significances. The current draw for each input line is between 5 and 15 mA.

[Figure 6](#) shows an example of a typical circuit you can use to input a signal into the camera.

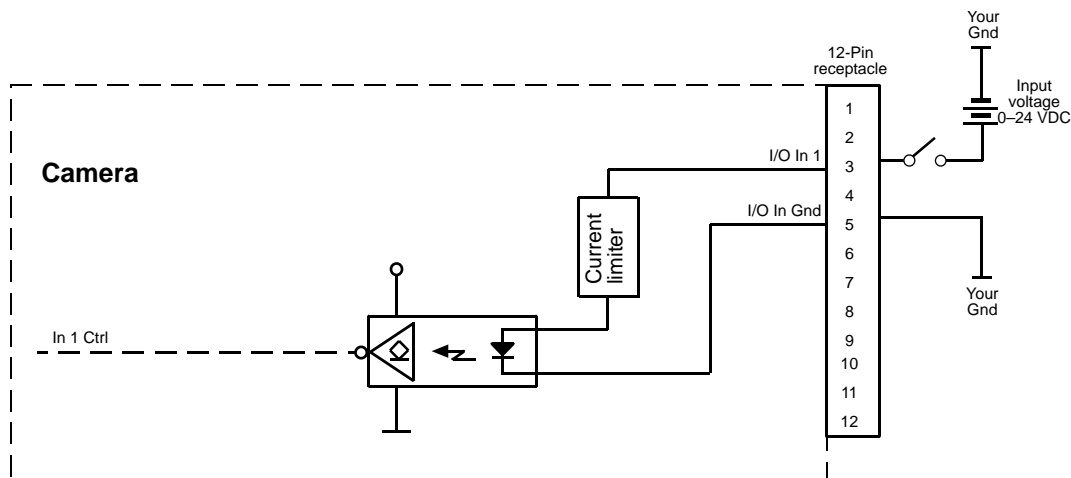


Fig. 6: Typical Input Circuit (Simplified)

For more information about input line pin assignments and pin numbering, see [Table 3](#) on [page 16](#).

4.3.3 Using an Input Line to Send a Hardware Trigger Signal

You can use input line 1 or input line 2 to send a hardware trigger signal to the camera. The hardware trigger can be used to trigger the acquisition start.

When using hardware trigger signals, make sure that the electric signal applied to the input line is appropriately timed for the function.

For more information about using input lines to send a hardware trigger signal and timing requirements, see [Section 5.1](#) on [page 24](#).

4.4 Output Line Description

4.4.1 Voltage Requirements

The following voltage requirements apply to the I/O output VCC (pin 10 of the 12-pin connector):

Voltage	Significance
<3.3 VDC	The I/O outputs may operate erratically.
3.3–24 VDC	Operating voltage.

Table 5: Voltage Requirements for the I/O Output VCC

4.4.2 Characteristics

The camera is equipped with two physical output lines designated as output line 1 and output line 2. The output lines are accessed via the 12-pin connector at the back of the camera.

As shown in the I/O schematic, each output line is opto-isolated. See Section 4.4.1 on [page 21](#) for the recommended operating voltage. **The maximum current allowed through an output circuit is 50 mA.**

A logical zero on Out X Ctrl results in a non-conducting transistor Q in the Output Line X circuit, where X stands for the number of an output line. For example, a logical zero on Out 1 Ctrl results in a non-conducting transistor Q in the Output Line 1 circuit.

A logical one on Out X Ctrl results in a conducting transistor Q in the Output Line X circuit, where X stands for the number of an output line. For example, a logical one on Out 1 Ctrl results in a conducting transistor Q in the Output Line 1 circuit.

[Figure 7](#) shows a typical circuit you can use to monitor the output line with a voltage signal.

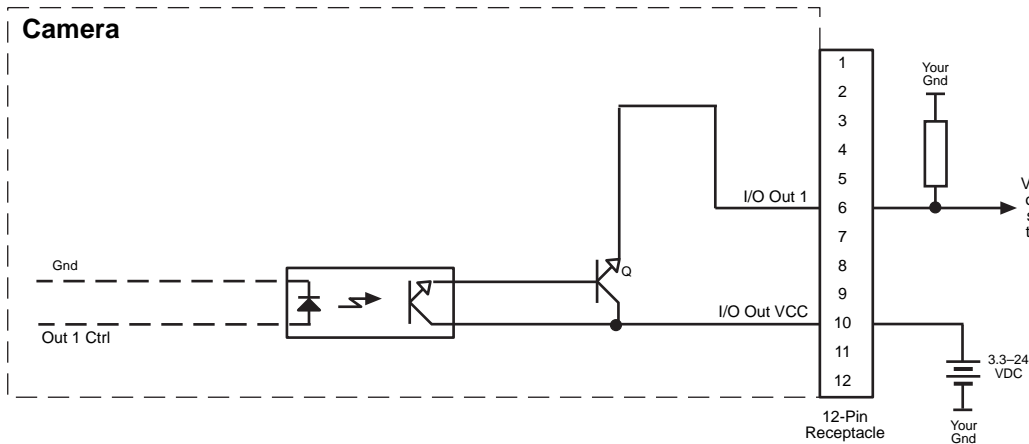


Fig. 7: Typical Voltage Output Circuit (Simplified)

Figure 8 shows a typical circuit you can use to monitor an output line with an LED or an opto-coupler. In this example, the voltage for the external circuit is 24 VDC. Current in the circuit is limited by an external resistor.

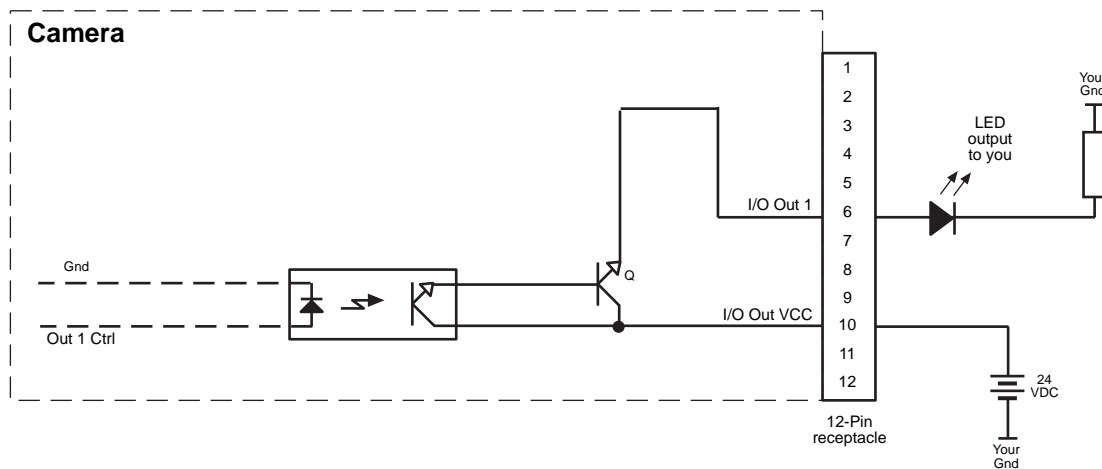


Fig. 8: Typical LED Output Signal (Simplified)

For more information about

- output line pin assignments and pin numbering, see Section 4.1.1 on [page 16](#).
- configuring the output lines, see Section 4.4.4 on [page 23](#).

4.4.3 Response Times

Response times for the output lines of the camera are as shown in [Figure 9](#).

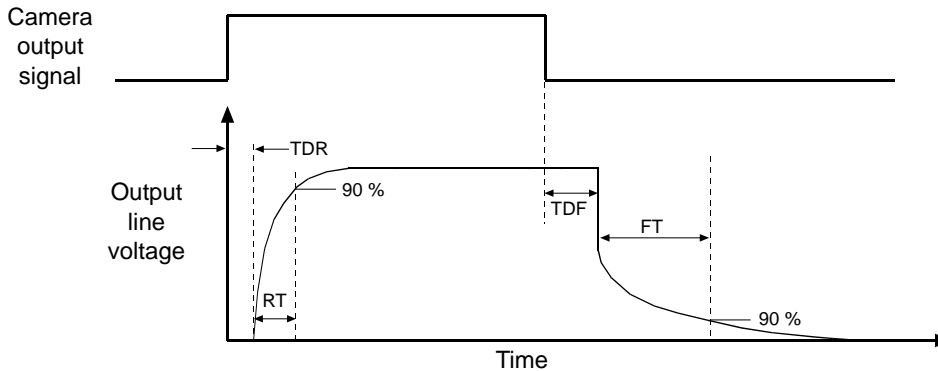


Fig. 9: Output Line Response Times

Time Delay Rise (TDR) = 1.5 μ s (typical)

Rise Time (RT) = 1.0 - 2.0 μ s (typical)

Time Delay Fall (TDF) = 40 μ s (typical)

Fall Time (FT) = 5 - 10 μ s (typical)



The response times for the output lines of your camera will typically fall into the ranges specified above. The exact response time for your specific application will depend on the external resistor and the applied voltage you use.

4.4.4 Assigning a Camera Output Signal to an Output Line

To make a physical output line useful, you must select a source signal for the output line. The camera has several standard output signals available and each signal can be selected as the source signal for an output line.

5 I/O Control

This section describes how to configure the camera's two input lines and two output lines. It also provides information about monitoring the state of the input and output lines.

5.1 Configuring Input Lines

5.1.1 Using an Input Line to Send a Hardware Trigger Signal

The camera is equipped with two physical input lines designated as input line 1 and input line 2. You can use a camera input line to act as the source signal for the acquisition start trigger. This also allows you to trigger two or more cameras simultaneously.

If an input line is configured as the source signal for the acquisition start trigger, whenever an appropriate electrical signal is applied to the line, the camera will recognize the signal as an acquisition start trigger signal.

For more information about the electrical characteristics of input lines, see Section 4.3 on [page 19](#).



Triggering multiple cameras simultaneously may cause network congestion and lead to data packets being dropped. To find out how to prevent this, see Section 8.8 on [page 61](#).

5.1.2 Input Line Debouncers

The debouncer feature aids in discriminating between valid and invalid input signals and only lets valid signals pass to the camera. The debouncer value specifies the minimum time that an input signal must remain high or remain low in order to be considered a valid input signal.



Basler recommends setting the debouncer value so that it is slightly higher than the longest expected duration of an invalid signal.

Setting debouncer values too low or too high will have the following results:

- debouncer value too low = invalid signals will be accepted
- debouncer value too high = valid signals will be rejected

Note that the debouncer delays a valid signal between its arrival at the camera and its transfer. The duration of the delay will be determined by the debouncer value.

Default value: 10 μ s

Figure 10 illustrates how the debouncer filters out invalid input signals, i.e. signals that are shorter than the debouncer value. The diagram also illustrates how the debouncer delays a valid signal.

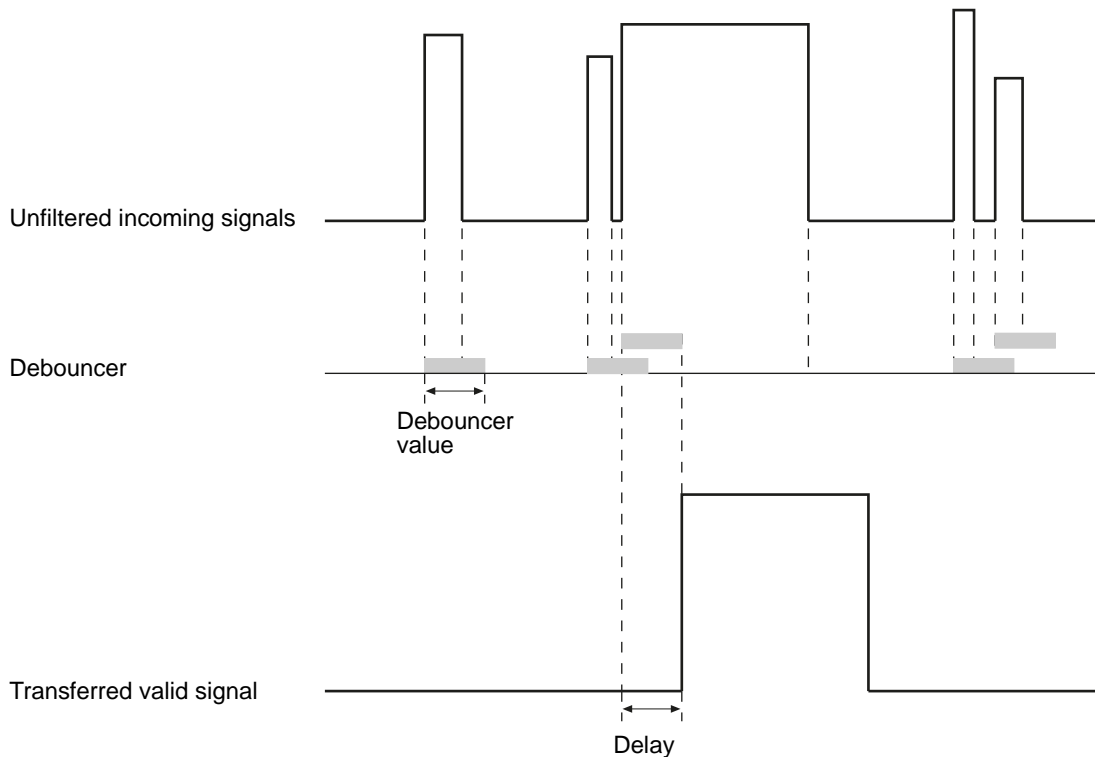


Fig. 10: Filtering of Input Signals by the Debouncer

Configuring the Debouncer

The debouncer value on each line is determined by the value of the **Line Debouncer Time** parameter value. The parameter is set in microseconds.

To configure the debouncer:

1. In the **Digital IO Control** group, select an input line using the **Line Selector** drop-down box.
2. Set the **Line Debouncer Time** parameter to the desired value.

You can select the input line and set the value of the **Line Debouncer Time** parameter from within your application software by using the API that is supplied with the Basler ToF Driver package.

The following code snippet shows how to set the debouncer to 10 using the API.

```
GenApi::CEnumerationPtr ptrLineSelector =  
camera.GetParameter("LineSelector");  
ptrLineSelector->FromString("Line1");  
  
GenApi::CFloatPtr ptrLineDebouncerTime =  
camera.GetParameter("LineDebouncerTime");  
ptrLineDebouncerTime->SetValue(10);
```

5.1.3 Using an Input Line to Receive a User Input Signal

You can also use an input line to receive your own, user-generated input signal. The electrical characteristics of your input signal must meet the requirements shown in Chapter 4 on [page 15](#).

You can use the **Line Status** or **Line Status All** parameters to monitor the state of the input line that is receiving the user-defined signal.

For more information about using the Line Status and Line Status All parameters, see Section 5.3.1 on [page 30](#).

5.1.4 Inverting the Electrical Signal Arriving at an Input Line

You can invert the electrical signal arriving at an input line.

To invert the electrical signal arriving at an input line:

1. In the **Digital IO Control** group, select an input line using the **Line Selector** drop-down box.
2. Select the **Line Inverter** parameter to enable inversion or deselect it to disable inversion.

You can invert the electrical signal arriving at an input line from within your application software by using the API that is supplied with the Basler ToF Driver package.

The following code snippet shows how to enable inversion on line 1.

```
GenApi::CEnumerationPtr ptrLineSelector = camera.GetParameter("LineSelector");  
ptrLineSelector->FromString("Line1");  
GenApi::CBooleanPtr ptrLineInverter = camera.GetParameter("LineInverter");  
ptrLineInverter->SetValue(true);
```

5.2 Configuring Output Lines

5.2.1 Assigning a Camera Output Signal to an Output Line

The camera is equipped with two output lines designated as output line 1 and output line 2. You can use the camera's output signal selection capability to select one of the camera's standard output signals as the source signal for a physical output line. The camera has several standard output signals available:

- Acquisition Trigger Wait
- Exposure Active
- User Output

You can also designate an output line as "user settable". If an output line is designated as user settable, you can use the camera's API to set the state of the line as desired.

To select a source signal for an output line or to make the line user settable:

1. In the **Digital IO Control** group, select an output line using the **Line Selector** drop-down box.
2. Set the value of the **User Output Selector** parameter to **User Settable Output**.

You can configure the **Line Selector** and **User Output Selector** parameter from within your application software by using the API that is supplied with the Basler ToF Driver package.

The following code snippets show how to make output line 1 user settable.

```
// Select output line 1
GenApi::CEnumerationPtr ptrLineSelector =
camera.GetParameter("LineSelector");
ptrLineSelector->FromString("Out1");
// Make output line 1 user settable
GenApi::CEnumerationPtr ptrUserOutputSelector =
camera.GetParameter("UserOutputSelector");
ptrUserOutputSelector->FromString("UserOutput1");
```

For more information about configuring the state of a user settable output line, see Section 5.2.2 on [page 28](#).

For more information about the electrical characteristics of output lines, see Section 4.4 on [page 21](#).

5.2.2 Configuring the State of a User Settable Output Line

As mentioned in the previous section, you can designate an output line as "user settable". If you have designated an output line as user settable, you can use camera parameters to set the state of the line.

To configure the state of a user settable output line:

1. In the **Digital IO Control** group, select an output line using the **Line Selector** drop-down box.
2. Set the **Line Source** parameter to the desired value.
3. In the **User Output Selector** drop-down box, select the desired value.
4. Select the **User Output Value** check box.

If the check box is selected, the output line will be user settable.

You can set the **Output Selector** and the **User Output Value** parameters from within your application software by using the API that is supplied with the Basler ToF Driver package.

The following code snippets show how to set the state of user settable output line 1.

```
// Make output line 1 user settable
GenApi::CEnumerationPtr ptrLineSelector =
camera.GetParameter("LineSelector");
ptrLineSelector->FromString("Out1");
GenApi::CEnumerationPtr ptrUserOutputSelector =
camera.GetParameter("UserOutputSelector");
ptrUserOutputSelector->FromString("UserOutput1");
```

```
// Set the state of output line 1
GenApi::CBooleanPtr ptrUserOutputValue =
camera.GetParameter("UserOutputValue");
ptrUserOutputValue->SetValue(true);
```



If you have the invert function enabled on the output line and the line is made user settable, the user setting sets the state of the line before the inverter.

5.2.3 Inverting the Output Line Signal

You can choose to invert the signal of an output line.

When an output line signal is not inverted (where X is the output line number):

- A logical zero on Out_X_Ctrl results in a non-conducting transistor Q in the output circuit.
- A logical one on Out_X_Ctrl results in a conducting transistor Q in the output circuit.

For example in [Figure 11](#), a logical zero on Out_1_Ctrl results in a non-conducting transistor Q in the line 1 output circuit, and a logical one results in a conducting transistor Q.

When the output line signal is inverted:

- A logical zero on Out_X_Ctrl results in a conducting transistor Q in the output circuit.
- A logical one on Out_X_Ctrl results in a non-conducting transistor Q in the output circuit.

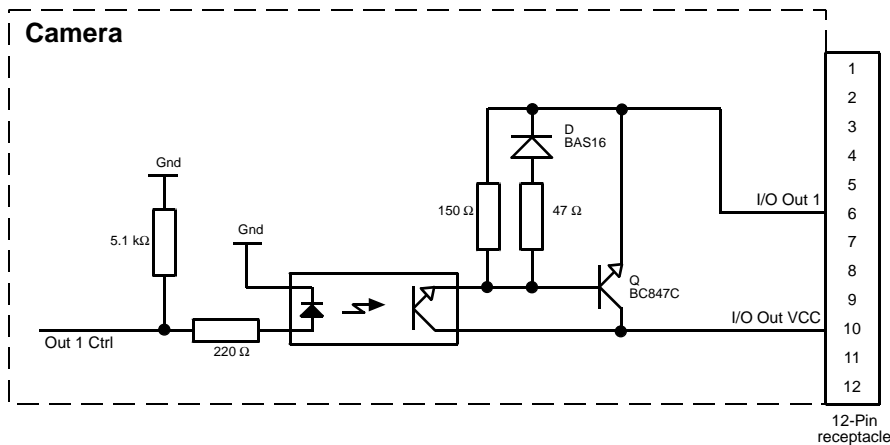


Fig. 11: Output Line Schematic for Line 1

To invert the output line signal:

1. In the **Digital IO Control** group, select an output line using the **Line Selector** drop-down box.
2. Select the **Line Inverter** parameter to enable inversion or deselect it to disable inversion.

You can invert the output line signal from within your application software by using the API that is supplied with the Basler ToF Driver package.

The following code snippet shows how to enable the inverter on output line 1.

```
GenApi::CEnumerationPtr ptrLineSelector =  
camera.GetParameter("LineSelector");  
ptrLineSelector->FromString("Out1");  
GenApi::CBooleanPtr ptrLineInverter =  
camera.GetParameter("LineInverter");  
ptrLineInverter->SetValue(true);
```

5.3 Checking the State of I/O Lines

5.3.1 Checking the State of I/O Lines or of a Single Line

You can determine the current state of any of the camera's I/O lines, either individually or all at once.

To check the state of a single line:

1. Use the **Line Selector** drop-down box to select the line.
2. Read the value of the **Line Status** parameter to determine the current state of the line.
A value of true means the line's state is currently high and a value of false means the line's state is currently low.

You can check the **Line Status** parameter value from within your application software by using the API that is supplied with the Basler ToF Driver package.

The following code snippet shows how to get the state of output line 1.

```
GenApi::CEnumerationPtr ptrLineSelector =  
camera.GetParameter("LineSelector");  
ptrLineSelector->FromString("Out1");  
GenApi::CBooleanPtr ptrLineStatus = camera.GetParameter("LineStatus");  
std::cout << "Value of LineStatus is " << ptrLineStatus->GetValue() <<  
std::endl;
```

To check the state of all lines:

1. Get the value of the **Line Status All** parameter.

You can get the **Line Status All** parameter value from within your application software by using the API that is supplied with the Basler ToF Driver package.

The following code snippet shows how to get the state of all lines.

```
GenApi::CIntegerPtr ptrLineStatusAll =
camera.GetParameter("LineStatusAll");
std::cout << "Value of LineStatusAll is "
<< ptrLineStatusAll->GetValue() << std::endl;
```

The **Line Status All** parameter is a 32-bit value. As shown in [Figure 12](#), certain bits in the value are associated with each line, and those bits indicate the state of the lines. If a bit is 0, it indicates that the state of the associated line is currently low. If a bit is 1, it indicates that the state of the associated line is currently high.

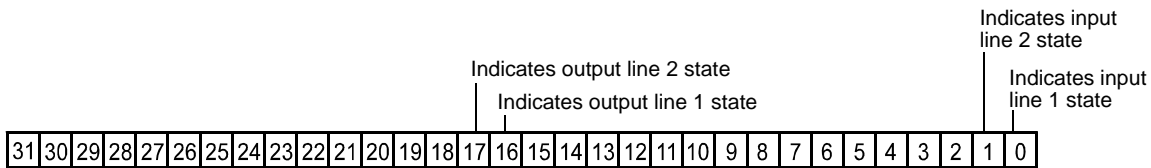


Fig. 12: Line Status All Parameter Bits

6 Time-of-Flight Concepts

Based on the Time-of-Flight (ToF) principle, the Basler ToF Camera can measure distances by sending out light pulses from an integrated light-source and measuring the time the light pulses take to travel back to the camera's sensor. Simply speaking, the longer it takes for the reflected light pulse to reach the sensor, the greater the distance to the object, and vice versa.

In the following sections, ToF distance measurement and associated challenges are explained in more detail.

6.1 Distance Measurement with Basler ToF Cameras

The ToF camera uses pulsed light from infrared LEDs to illuminate a target. These light pulses are reflected by the target and registered by the sensor. The sensor then converts the electrical charge created by the light energy in the sensor's pixels into distance information. Following is a simplified description of how this works.

When the camera is triggered, the LEDs all light up simultaneously for a specified period of time (t_p) and the energy reflected back from the target is collected at every pixel of the sensor using two shutter windows with the same t_p :

- Shutter window S0
Opens when light pulse starts.
- Shutter window S1
Opens when light pulse ends.

The process of light pulses being emitted and shutter windows opening and closing happens repeatedly until the specified exposure time has been completed.

Figure 13 illustrates how the shutter windows open in relation to the light pulses. The principle how distance can be calculated from the data gathered is expressed in the following formula:

$$d = \frac{c}{2} t_p \left(\frac{S1}{S0 + S1} \right)$$

where:

d = distance

c = speed of light

t_p = period of time that the light pulse is active

S0 = electric charge gathered during first shutter window S0

S1 = electric charge gathered during second shutter window S1

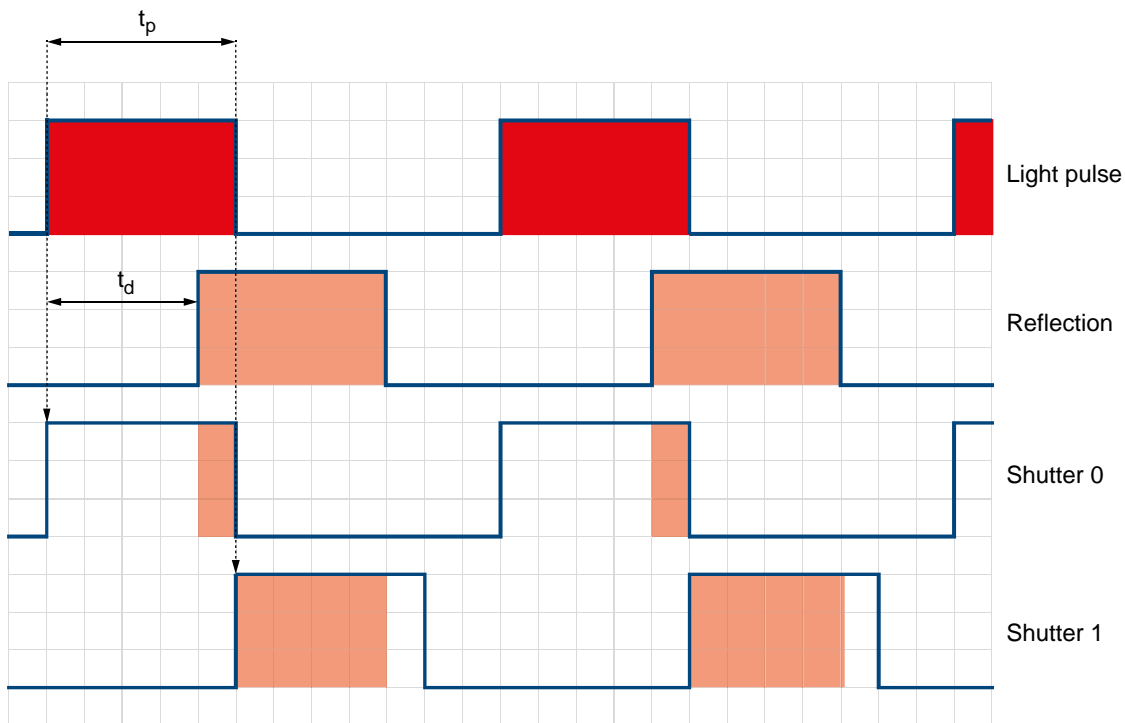


Fig. 13: Time of Flight Distance Measurement Using Pulsed Light

6.1.1 Accuracy and Repeatability

Basler ToF Cameras are calibrated for a measurement range of 0.5–5 m. Within that range, the camera's performance can be characterized by the following criteria:

- Absolute accuracy

Absolute accuracy is the mean difference between the measured distance and the true distance. To achieve a result as accurate as possible, Basler ToF Cameras are calibrated at the factory and tested to guarantee a reliable accuracy.
- Repeatability

The repeatability indicates the spread of the measured values around the mean value.

Accuracy and repeatability are measured under the following uniform conditions:

- camera model 107002-07 with default settings
- default channel
- 20 minutes camera warm-up time
- sheet of white paper as target object
- no ambient light
- 22 °C room temperature
- 40 x 40 pixels in the center of the range map
- 25 images
- offset corrected

The testing carried out on Basler ToF Cameras has proved the accuracy to be ± 1 cm. This is illustrated in [Figure 14](#).

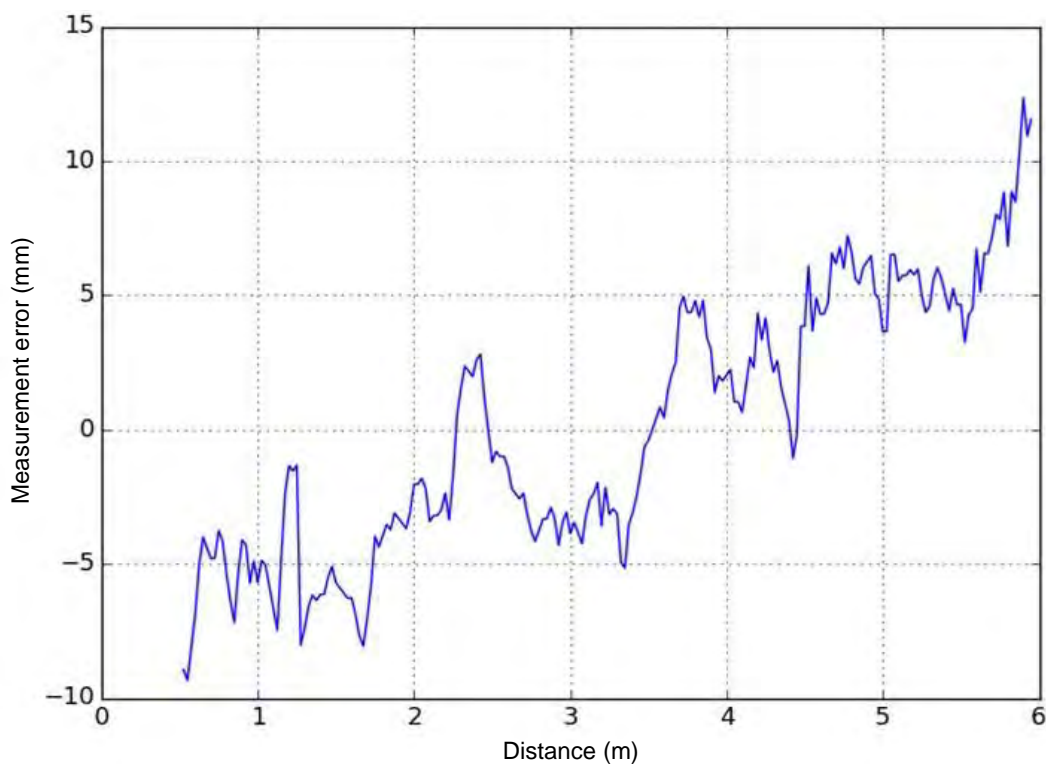


Fig. 14: Accuracy Measurement for the Basler ToF Camera

6.2 Influencing Factors

6.2.1 Ambient Light

As the ToF distance measurement relies on the reflection of light sent out by the camera, any additional light, e.g. artificial light sources or sunlight, can influence the measurement results.

While the camera is able to measure the ambient light and then subtract it from the total light energy the pixels receive, there is a limit to the camera's ability to compensate for ambient light. The reason is that a pixel can only accept a certain amount of electrical charge. If this capacity is used up by ambient light, less space is available for the intended light pulse reflection and, as a consequence, the signal-to-noise ratio decreases.

To mitigate the influence of ambient light, an optical bandpass filter is used. As this filter only allows light of the same spectrum as the camera's light source to pass through to the sensor, artificial light sources are usually not a big problem as they operate in a different spectrum.

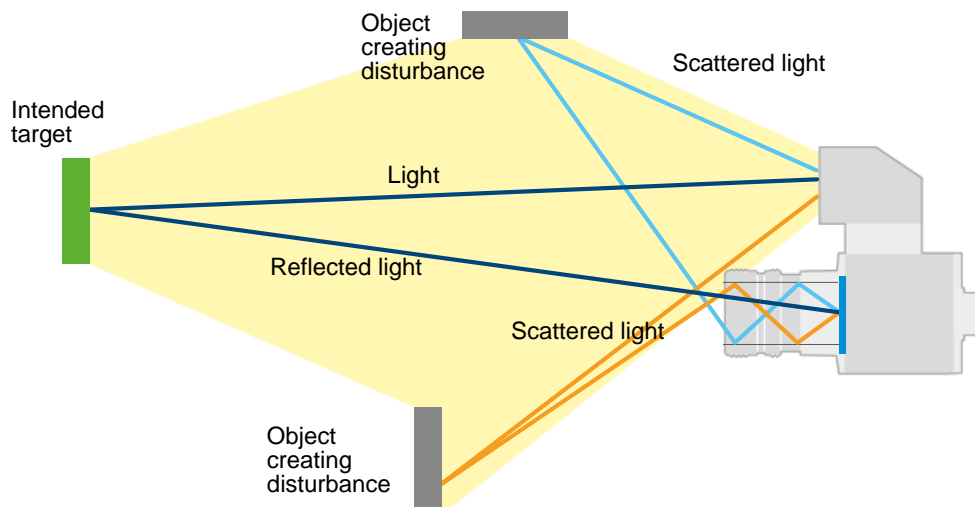
Sunlight, however, is active across the whole light spectrum and can create significant light energy, on a sunny day for example. Therefore, measures need to be taken to protect the camera from over-exposure in order to make sure that the intended reflection can be measured.

For tips how to best plan your camera setup in order to avoid over-exposure, see [page 45](#).

6.2.2 Scattered Light

Reflections inside the camera lens or behind it, can create scattered light. Even though great care is taken during the manufacture of the Basler ToF Camera, for example by using special non-reflective coating for internal components, these reflections can't be eliminated completely.

Scattered light is also easily generated by bright surfaces in the immediate vicinity of the light source. These surfaces don't even need to be in the direct field of view of the sensor to create problems. Just by placing the camera in the middle of a tabletop, the light from the camera may be reflected by the tabletop straight back into the lens and can thus skew the distance measurement. The following figure illustrates these effects.



To combat the effects of scattered light, Basler has taken the following measures:

- Careful selection of lenses
- Limited aperture of the light source
- Use of a lens hood

For tips how best to plan your camera setup in order to avoid the creation of scattered light, see [page 45](#).

6.2.3 Temperature

Temperature has a big influence on achieving reliable distance measurements. There are different aspects of this to consider:

- Camera requires stable temperature.

Measurement accuracy fluctuates with changes in temperature, even if the overall temperature is within the allowed temperature range. To achieve best possible results, the temperature should be kept stable. For recommendations on how to do this, see Section 3.7.2 on [page 11](#).
- Camera requires warm-up time.

The camera needs approx. 20 minutes to achieve a stable operating temperature. As a stable temperature is a prerequisite for accurate measurements, allow 20 minutes before starting to acquire images.
- Observe the operating temperature range (see Section 3.7.1 on [page 11](#)).

At temperatures above 50 °C, reliable camera operation can't be guaranteed anymore. At housing temperatures below 0 °C, the camera won't start.
- Consider temperature drift.

The mean error varies with the target distance of the measurement and the temperature. For more details, see the following section.

Temperature Drift

The behavior of the Basler ToF Camera at different temperatures and measuring distances is a complex subject. Under laboratory conditions, extensive tests have been carried out, and the results of these tests may help you to improve the accuracy of your measurements.

Figure 15 shows how the temperature drift, or offset error, varies.

The x axis shows the change in temperature over the test series from -20–70 °C. The blue curve is the environment temperature (simply measured by a thermometer placed in the room where the camera is located). The green curve shows the temperature at the sensor board (measured by the internal temperature sensor of the camera).

The y axis shows by how much the distance measured differs from the actual distance. This is the mean measurement error or offset error. As a rule of thumb, at higher temperatures, the distances measured by the camera are shorter than the actual distances.

In order to improve your measurement results you could try factoring in the temperature drift. To make this easier for you, the drift information has been compiled in Table 6 and Table 7. To obtain the correct result, add the offset to the distance measured.

Note that these figures are based on tests carried out with one camera only. It is quite likely that your camera behaves differently. Therefore, they can serve as a guideline only.

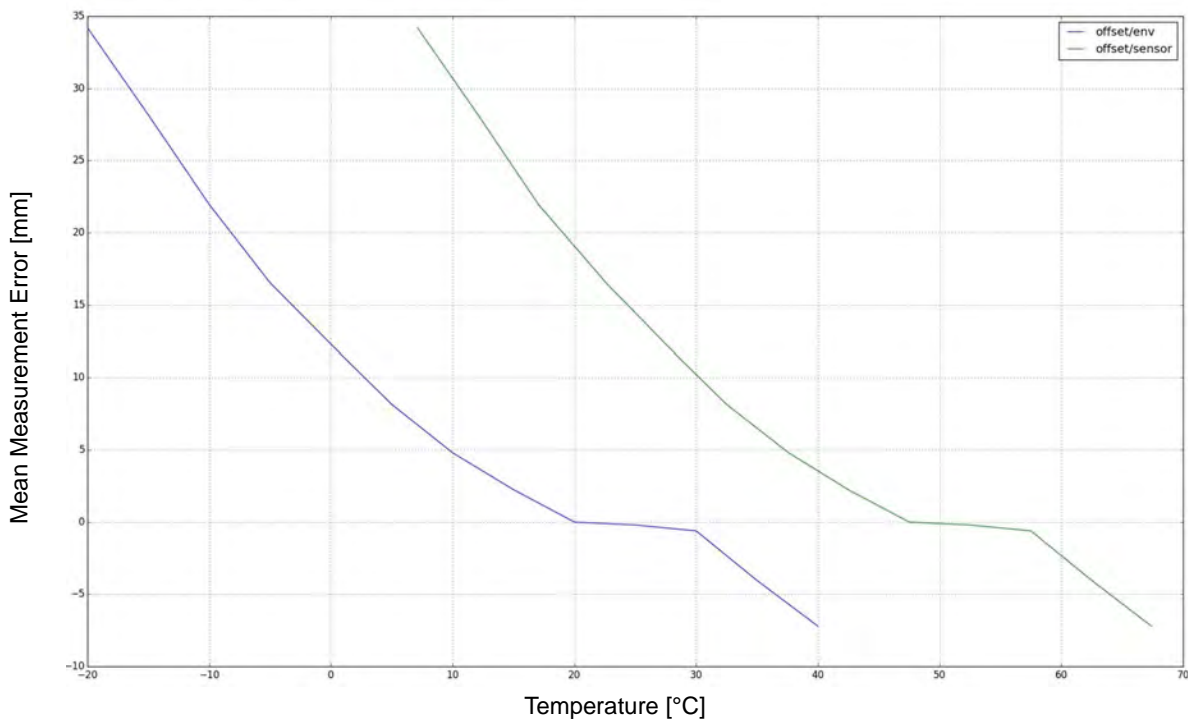


Fig. 15: Temperature Drift

Environment Temperature [°C]	Offset [mm]
-20	-34.2
-15	-28.2
-10	-22.0
-5	-16.5
0	-12.3
5	-8.1
10	-4.8
15	-2.2
20	0.0
25	0.2
30	0.6
35	4.0
40	7.2

Table 6: Measurement Error in Relation to Environment Temperature

Sensor Temperature [°C]	Offset [mm]
7.1	-34.2
12.1	-28.2
17.0	-22.0
22.6	-16.5
27.5	-12.3
32.5	-8.1
37.6	-4.8
42.5	-2.2
47.5	0.0
52.5	0.2
57.5	0.6
62.5	4.0
67.4	7.2

Table 7: Measurement Error in Relation to Sensor Temperature

6.2.4 Multiple Reflections (Multipath)

For accurate distance measurement, only light reflected **once** delivers reliable data. Any light that has been reflected several times, by other objects in the camera's field of view or the environment in general, can falsify the measurement. Concave forms, like corners of a room or the inside of a coffee cup, are particularly problematic as the light pulse can bounce back and forth between the different surfaces, thus increasing the time until it is received by the sensor.

Mirrors and highly-reflective surfaces, e.g. lacquered tabletops, can also lead to multiple reflections or can even deflect the light pulse completely. The following figure illustrates these effects.

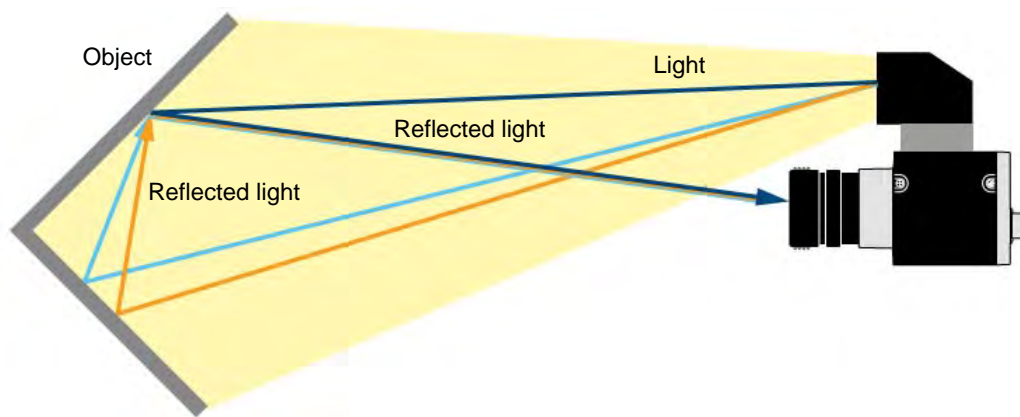


Fig. 16: Multipath Effects

For tips how best to plan your camera setup in order to avoid multiple reflections, see [page 45](#).

6.2.5 Reflectivity of Target Objects

The reflectivity of the target object also has an influence on the accuracy of the measurement. Two aspects need to be considered:

- Reflection type determined by the surface quality of the target object
- Target object color

Reflection Type

Two kinds of reflection can occur:

- Diffuse reflection

This occurs in matte objects (e.g., wood or paper). Reflectance is uniform which means that the light pulses are reflected equally at all angles. In contrast to specular reflections described below, this kind of reflection is preferable because the intensity of the light reflected back into the sensor isn't influenced by the angle.

- Specular reflection

This occurs in glossy objects (e.g., polished metal or, in extreme cases, mirrors) and transparent materials. Reflection will occur according to the law of reflection which states that incoming light of a certain direction will be reflected into one outgoing direction, with incoming and outgoing light pulses at equal angles to the perpendicular of the object surface. This means that the reflected light pulse will follow a different path than the light pulse sent out by the camera which can lead to multiple reflections. For more information about multiple reflections, see [Section 6.2.4](#) above.

The other danger is that the reflected light hits the sensor directly which occurs when the light pulse hits the perpendicular of the object surface. This can lead to the pixels becoming saturated with the energy from a single light pulse.

For the above reasons, accurate distance measurement of glossy or transparent materials is difficult.

Target Object Color

Bright objects provide better results as, generally speaking, they are able to reflect more light, whereas with dark objects a certain amount of light is absorbed which will therefore not be returned back to the sensor.

Another aspect to consider is the distance of the object from the sensor. While bright objects generally yield more accurate results, if they are placed close to the sensor, they reflect back so much light that oversaturation occurs. Once pixels become oversaturated, they don't contribute to the distance measurement anymore. As a result, the measurement quality decreases.

You also need to be aware that the camera works with near-infrared light, and it is very difficult to predict whether an object actually reflects the near-infrared light well enough. Therefore, the distinction made above can only serve as a general rule of thumb.

The intensity image can help you to assess the accuracy of your measurements. Objects that are well illuminated without being under- or oversaturated in the intensity image, will produce accurate measurement results.

For more information about the intensity image, see [page 52](#).

6.2.6 Non-Ambiguity

The non-ambiguity range of the Basler ToF Camera is 0–13.320 m. This means that distances of objects measured in this range reflect the object's true distance.

The problem of ambiguity arises beyond 13.320 m as the camera considers this an undefined area. The effect is that every 13.320 m a new measurement interval starts again at 0 m. This is inherent in the camera because of the timing pattern of the light pulses.

Because the light pulses can travel beyond the non-ambiguity range, objects in this undefined area will also reflect back light that will be registered by the camera's sensor. To deal with this, the camera "folds back" the results into the non-ambiguity range.

For example, objects at 1 m outside the range will appear at 1 m within the non-ambiguity range. In other words, if the object is 14.320 m away from the camera, its distance is measured as 1 m.

The following figure illustrates this.

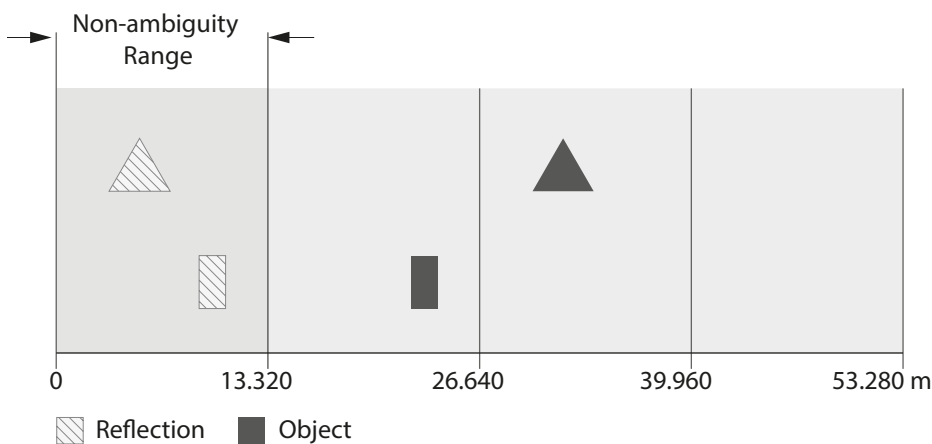


Fig. 17: Folding Back of Objects into the Non-ambiguity Range

Unless there are highly-reflective objects or retroreflectors in the camera's field of view, this shouldn't cause major problems. Most objects won't be able to reflect back sufficient light to be registered by the camera's sensor over distances beyond 13.320 m. Therefore, if you ensure that no highly-reflective objects or retroreflectors are placed within your scene, you can almost completely avoid ambiguous results.

Another option to ensure that objects outside the non-ambiguity range don't influence the results is to use the confidence map. For example, by setting an appropriate confidence threshold you can filter out far away objects. For more information, see [page 53](#).

Changing the region of interest (ROI) may also be a useful tool for reducing ambiguous results as it reduces the available measurement range. For more information, see Section 8.2 on [page 50](#).

7 Installation

7.1 Software Installation

To operate the Basler ToF Camera, you need the software package appropriate for your operating system. For more information about the software, see [page 10](#).

If you install the software, the following components will be installed:

- ToF Viewer (Windows only)

The ToF Viewer is a standalone application that has been specifically developed to operate the Basler ToF Camera under Windows operating systems. It allows you to change the camera's parameters and to view and manipulate the individual image components that the camera delivers, i.e., the range data, confidence image, and point cloud.

In the **Documentation** pane, it also contains useful code snippets for when you are programming using the API.

For more information about using the ToF Viewer, see the ToF Viewer online help.

- pylon Viewer (ToF); (Linux only)

The pylon Viewer is a standalone application that lets you view and change the camera's parameter settings under Linux operating systems.

- ToF IP Configurator

The IP Configurator shows you the current IP configuration of your camera and network adapter and allows you to change it.

- GenTL Producer

The GenTL Producer provides interoperability with third-party image processing libraries.

- Code samples

The installation folder contains a set of code samples that illustrate how to use the camera's API.

- ToF Programmer's Guide (HTML and PDF version)

The ToF Programmer's Guide can be used in conjunction with the code samples to write code for the Basler ToF Camera.



Updates are being made available at irregular intervals on the Basler website. If you experience problems with using the software, check the Basler website for updates.

If you need assistance with installing or using the software, contact Basler Support under the e-mail address support.europe@baslerweb.com.

7.1.1 Installing the Basler ToF Driver Software on Windows Operating Systems

To install the Basler ToF Driver software:

1. Close all open applications on your computer.
2. Navigate to the location of the ToF Driver installer, and double-click the .exe file.
The installation will be prepared and a window with the license agreement will open.
3. Accept the licensing terms by selecting the check box.
 - a. If you want to change the default installation directory, click **Options** and navigate to the desired location using the **Browse** button.
 - b. Click **OK**.
4. Click **Install**.
A message will be displayed when the installation has completed.
5. Click **Close**.
Note that the installation program has added shortcuts for the installed features on the desktop.

7.1.2 Installing the Basler ToF Driver Software on Linux Operating Systems



You have to install the version of the Basler ToF Driver software appropriate for your operating system. If you install the 32-bit version on a 64-bit operating system, the software will not run, and vice versa.

The installation procedure described below assumes that you are going to install the Basler ToF Driver software in the **/opt/BaslerToF** directory. If you choose to install in a different location, you'll have to modify the directory names accordingly.

You need root permissions to write to **/opt**.

To install the Basler ToF Driver software:

1. Uninstall any previously installed ToF Driver software.
The ToF Driver and pylon can coexist but older versions of the ToF Driver need to be uninstalled first.
2. Extract the **basler-tof-driver-x.x.x-<ARCH>.tar.gz** archive to your home directory.

```
tar -C ~ -xzf basler-tof-driver-x.x.x-<ARCH>.tar.gz
```
3. Change to the directory which contains the INSTALL file, e.g.:

```
cd ~/BaslerToF-driver-x.x.x
```
4. Copy the BaslerToF directory to **/opt**.

```
sudo cp -r BaslerToF /opt
```
5. Execute the following command to test your cameras:

```
/opt/BaslerToF/bin/PylonViewerApp
```

7.2 Hardware Installation



To achieve reliable distance measurements, you might find the following tips useful:

- Avoid using the camera in bright sunlight. If possible, keep the ambient light below 15 kLux.
- Avoid placing any objects in the scene that are not part of your intended target, especially mirrors or other shiny surfaces/objects.
- Avoid placing the camera flat in the middle of a surface.
- Maintain a stable housing temperature during operation.
- Take measures to provide cooling.
- Mount the camera securely.

Before installing the camera, check the following:

- You have read and understood the warnings listed under "Precautions" on [page 2](#).
- Basler ToF Driver has been installed on your computer.
- All necessary accessories are present.

To install the camera:

1. Mount the camera in an appropriate fixture, e.g. a camera bracket.
2. Plug one end of the GigE cable into the RJ45 jack at the back of the camera, and plug the other end into the Ethernet port of your computer.
3. Insert the 12-pin plug of the power supply cable into the 12-pin connector at the back of the camera.
4. Insert the AC power plug of the power supply into a mains socket.

If the green LED lights up, the camera is ready for use.



It takes a while until the camera reaches a stable operating temperature. After 5 minutes there may still be a measurement error of 3–4 cm. After 20 minutes the distance measurement should be reliable.

NOTICE

Incorrect plugging in and unplugging of the camera's power cable can damage the camera.

To avoid switch-on surges damaging the camera, only plug in the power cable into the camera's 12-pin connector or unplug it from the connector if the power supply is switched off.

7.3 IP Address Configuration

By default, the camera is configured to use DHCP (Dynamic Host Configuration Protocol) to obtain an IP address. If no DHCP server is available or if your network adapter is configured differently, the camera will use automatic IP assignment as a fallback.

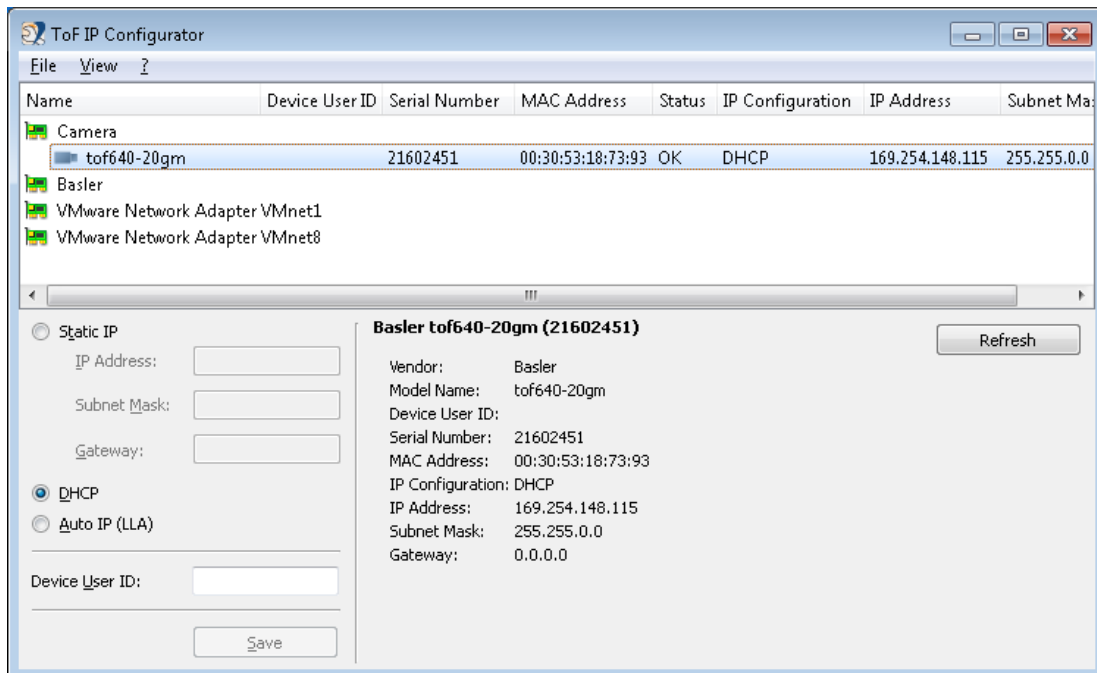
If the IP address assignment fails completely, you can manually assign an IP address using the ToF IP Configurator. The ToF IP Configurator shows you the current IP configuration of your camera and network adapter and allows you to change it.

To open the ToF IP Configurator:

1. **Windows:** Click **Start > All Programs > Basler > ToF Driver > ToF IP Configurator**.

Linux: Execute `/opt/BaslerToF/bin/IpConfigurator`.

The camera will be displayed under the network adapter.



For more information about the ToF IP Configurator, check the following documentation:

- ToF IP Configurator online help
The online help is available by pressing F1 in the ToF IP Configurator. Note that the online help is only available under Windows operating systems.
- *Installation and Setup Guide for Cameras Used with pylon for Windows* (AW000611)
This manual is available on the Basler website: www.baslerweb.com

8 Camera Operation

This chapter contains information about how to get started with the Basler ToF Camera. You will learn how to acquire images and get an introduction to the camera's parameter groups. Information on camera features is available in Chapter 9 on [page 62](#).



Two tools are available to operate the Basler ToF Camera:

- ToF Viewer (Windows only)
- pylon Viewer (ToF); (Linux only)

The main difference between the two tools is the way in which the image components are displayed. Any differences in use will be clearly marked in this chapter.

8.1 Acquiring Images

The easiest way to acquire the first images and to change the camera's settings is to use the ToF Viewer or pylon Viewer (ToF) software.

8.1.1 ToF Viewer

To start image acquisition:

1. Connect the camera to your computer.

For information on how to install the camera, see Section 7.2 on [page 45](#).

If the green LED at the back of the camera lights up, the camera is ready for use.

2. Start the ToF Viewer by clicking **Start > All Programs > Basler > ToF Driver > ToF Viewer**.

The camera appears in the camera selector drop-down box and image acquisition starts immediately.

In the image window area, four windows open that show the different image components. For more information about the image components, see Section 8.4 on [page 52](#).

If the camera is not shown in the camera selector, this may be due to problems with the IP address. IP address problems can be fixed using the ToF IP Configurator. For more information, see Section 7.3 on [page 46](#).

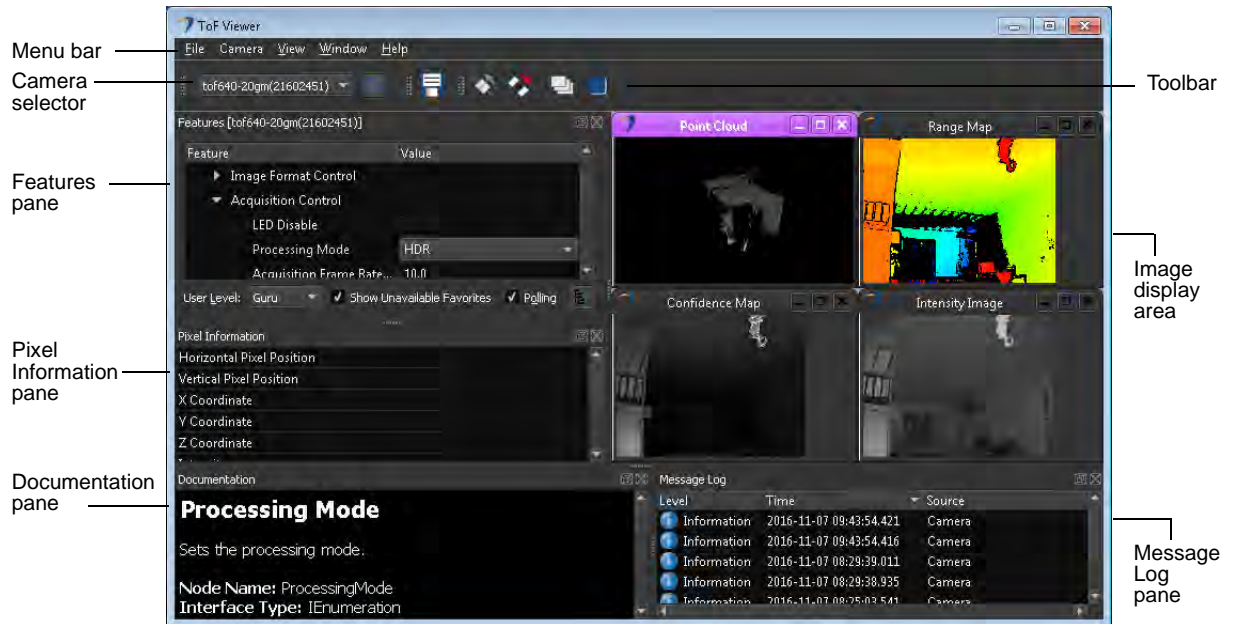



Fig. 18: ToF Viewer

	<p>If you have started the ToF Viewer in a remote desktop session and no image component windows are displayed, check your remote desktop client settings. The Colors setting needs to be set to Highest Quality (32 bit).</p>
--	--

8.1.2 pylon Viewer (ToF)

To start image acquisition:

1. Connect the camera to your computer.

See Section 7.2 on [page 45](#) for information on how to install the camera.

If the green LED at the back of the camera lights up, the camera is ready for use.

2. Start the pylon Viewer (ToF).

In the pylon Viewer (ToF), the camera will appear in the **Devices** pane under the **GigE GenTL (ToF)** node.

If the camera is not shown, this may be due to problems with the IP address. IP address problems can be fixed using the IP Configurator. For more information, see Section 7.3 on [page 46](#).

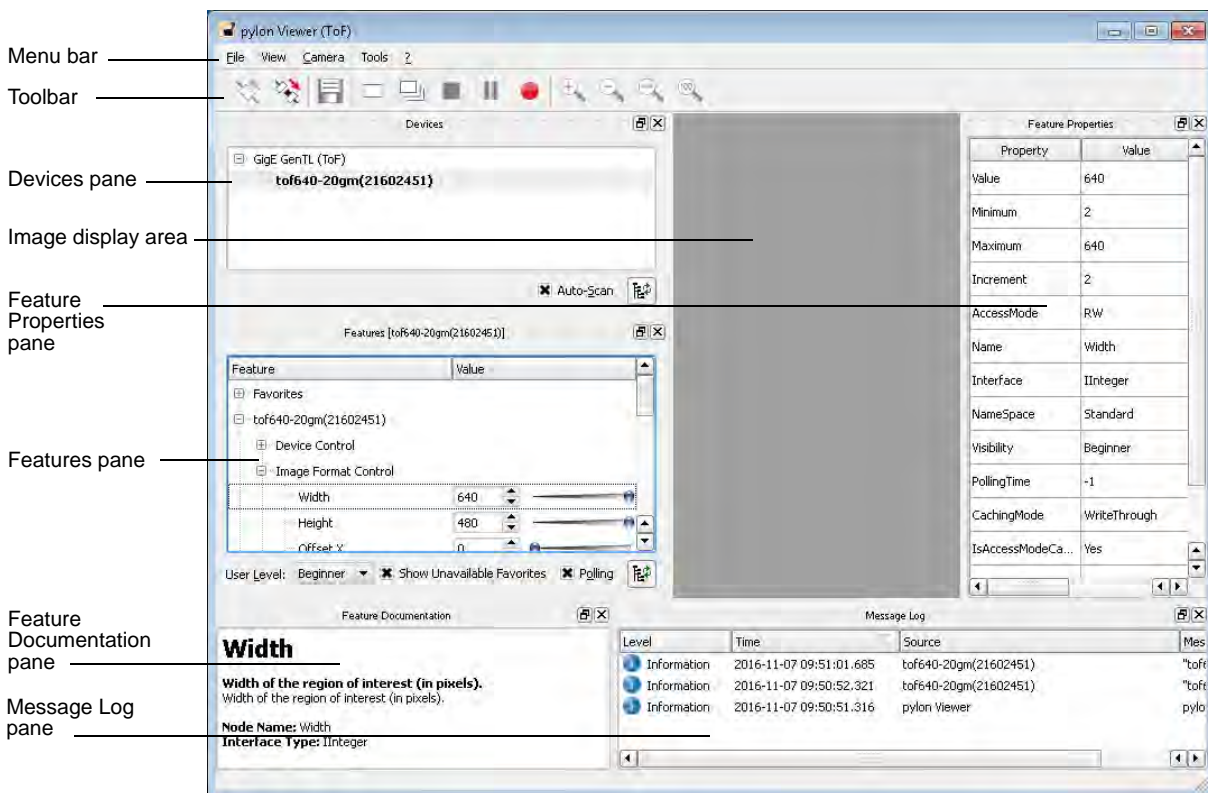


Fig. 19: pylon Viewer ToF

3. Select the camera in the **Devices** tree.
4. Open the camera by double-clicking it.
5. Start image acquisition by choosing **Continuous Shot** in the pylon Viewer (ToF).

An image will appear in the image display area. By default, this is the Mono 16 range map (Coord3D_C16). For more information about the image components, see Section 8.4 on [page 52](#).

8.2 Setting the Region of Interest (ROI)

You can set the size of the ROI using the **Width** and **Height** parameters, and you can change the position of the ROI using the **Offset X** and **Offset Y** parameters.

With the **Minimum Depth** and **Maximum Depth** parameters you can specify the radial distance aspect of the ROI. The available range is 0–13320 mm, which corresponds to the camera's non-ambiguity range (0–13.320 m). For example, with **Minimum Depth** set to 3000 and **Maximum Depth** set to 5000, the camera will acquire data in a distance from 3–5 m. Data from outside that range will be discarded.



Using the **Minimum Depth** and **Maximum Depth** parameters to define the ROI, and effectively reduce it, doesn't increase resolution or improve accuracy. This only increases the dynamic range of the gray values which results in enhanced contrast in the image.

Using the ROI to Reduce Ambiguous Results

As explained above, if you reduce the ROI, any data from beyond your ROI will be discarded. By choosing a ROI that fits your desired scene as closely as possible, you can thus minimize problems caused by ambiguous results.

For example, if your intended target is located between 3–5 m from the camera, set the **Minimum Depth** parameter to 3000 and the **Maximum Depth** parameter to 5000. This way, any light reflected from between 0–3 m and 5–13.320 m will be discarded. You may still get ambiguous results from the next interval (where the ROI would be between 15.320–18.320 m) but the impact should be negligible as long as there are no highly-reflective objects or retroreflectors in the camera's field of view.

For more information about ambiguity, see Section 6.2.6 on [page 41](#).

8.3 Acquisition Control

With the parameters in the **Acquisition Control** group you can control image acquisition.

- **LED Disable**

Switches off the camera's LEDs.

- **Processing Mode**

The processing mode determines whether the camera works in **Standard** mode, using one exposure time, or in **HDR** mode, using two exposure times. The default setting is **HDR**. For more information about the HDR feature, see Section 9.2 on [page 62](#).

- **Acquisition Frame Rate**

This is the output rate at which the GenTL producer generates images.

- **Exposure Auto**

This parameter controls whether automatic exposure control is used or not. If set to **Off**, the **Exposure Time** parameter controls the exposure duration. If set to **Continuous**, the exposure duration is constantly adapted by the camera to achieve the desired frame rate. Continuous exposure is only available in **Standard** processing mode. In **HDR** processing mode, the exposure times always have to be set manually.

The **Agility** parameter determines how quickly the continuous exposure mechanism reacts to changes in the scene captured. This has no effect if **Exposure Auto** is set to **Off**.



By continuously adjusting the exposure time, the automatic exposure control mechanism tries to create a balance between overexposed pixels (too bright) and underexposed pixels (too dark and not enough contrast). Whether a pixel is considered too dark is indirectly influenced by the **Confidence Threshold** parameter. For more information about this, see [page 53](#).

- **Exposure Time Selector**

Use this parameter to determine which exposure time you want to configure. If you're working in **Standard** processing mode, use exposure time 0. If you're working in **HDR** processing mode, use exposure time 0 and 1.

- **Exposure Time**

This parameter controls the exposure time if the **Processing Mode** parameter is set to **Standard** and the **Exposure Auto** parameter is set to **Off**. An exposure time of 15 ms means that to acquire one image, the camera sends out light pulses in quick succession for 15 ms.



Using manual exposure control can be useful if range maps taken with automatic exposure control show dark spots/areas as these may be due to oversaturation of sensor pixels. For an oversaturated sensor pixel the calculation of the depth isn't possible, which results in a black pixel in the range map.

8.4 Image Format Control

With the parameters in the **Image Format Control** group of the feature tree, you can define the region of interest (ROI) of your images (explained in Section 8.2 on [page 50](#)).

In the pylon Viewer (ToF), this is where you choose which type of data (or image component) the camera transmits. You can also specify the pixel format here.

The Basler ToF Camera generates three different image components.

■ Range data

This is the depth image. It represents the radial distance between the target and the camera per pixel. Strictly speaking, it is the time that passes between sending out a light pulse and the light pulse returning to the sensor. The following pixel formats are available:

■ **Coord3D_C16**

A monochrome image using unsigned 16-bit integer values (little-endian). Darker areas represent objects close to the camera while lighter areas represent objects farther away.

Note that objects outside of the camera's selected measurement range (in front or at the back of the ROI) will also appear black in the image.

■ **RGB8**

A false-color image for improved visualization. Red, green, and blue as 8-bit integer values (single plane) are used. Red areas represent objects close to the camera while blue areas represent objects farther away.

Note that objects outside of the camera's selected measurement range (in front or at the back of the ROI) will also appear black in the image.

■ **Coord3D_ABC32f**

This is the point cloud representation using 32-bit floating point values (single plane). Each point in the cloud holds three values representing the XYZ coordinates of the surface from which the light pulse has been reflected in a Cartesian coordinate system (in mm) in little-endian format. The image ordering is line by line and pixel by pixel.

The origin of the coordinate system is defined by the following positions:

- the **x** and **y** coordinates are 0 (zero) at the pixel at the center of the sensor
- the **z** coordinate is 0 (zero) at the front of the camera housing

For pixels with unreliable distance data (i.e., a low confidence value) or pixels that represent objects in the areas outside the ROI, the coordinates are NaN (Not a Number).

For more information about the camera's coordinate system, see Section 3.3 on [page 8](#).

■ Intensity image

The intensity image shows the brightness of the reflected light pulses (near-infrared and ambient light) as 16-bit integer values per pixel. Because the wavelength of the light sent out by the camera has an influence on this, the intensity image may differ from the human perception of the targeted scene.

The intensity image is useful for checking the image for over-/undersaturated pixels. To avoid these, try changing the exposure time or the camera position and check whether the image improves. The following pixel format is available:

- **Mono16**

A monochrome image using unsigned 16-bit integer values (little-endian).

- **Confidence map**

The confidence map represents a measure of how reliable the depth image data is. By analyzing the temporal variations of the light pulse signal, a 16-bit integer value per pixel is generated. The higher the value, i.e., the brighter the pixel, the more reliable the measurement. Light generated by the ToF camera itself and ambient light are considered when creating the confidence map. The following pixel format is available:

- **Confidence16**

A monochrome image using unsigned 16-bit integer values (little-endian).

You can set a confidence threshold using the **Confidence Threshold** parameter in the **Image Quality Control** parameter group. Pixels with values above the confidence threshold are deemed reliable. Values below the threshold will have their distance value set to zero or NaN (Not a Number) depending on the pixel format chosen for the range data.

Confidence Threshold and Automatic Exposure Control

The confidence threshold also indirectly influences the automatic exposure control. The automatic exposure control tries to create a balance between overexposed (too bright) and underexposed (too dark) pixels. As a result of a low confidence threshold, more dark pixels, with low contrast, will be considered reliable. In turn, the automatic exposure control will try to reduce the exposure time because dark pixels are acceptable.

8.4.1 Image Windows in the ToF Viewer

When starting image acquisition using the ToF Viewer, four windows are opened in the image display area. They show 3D and 2D views of the scene that the camera is capturing.

- **Point Cloud (3D)**

Each point in the cloud holds three values representing the XYZ coordinates of the point from which the light has been reflected.

By default, the point cloud is displayed utilizing the information from the intensity image, a gray value image representing the brightness of the reflected light pulses (near-infrared). Using the **Window** menu, you can open additional point cloud windows in color where the point cloud data is used for coloring near points red and far away points blue.

- **Range Map (2D)**

The range map is calculated from the point cloud data. By default, the range map is displayed in color. Using the **Window** menu, you can open additional range map windows in color or using gray values.

- **Intensity Image (2D)**

The intensity image shows the brightness of the reflected light pulses (near-infrared and ambient light). The closer an object is, the brighter it appears in the intensity image.

- **Confidence Map (2D)**

The confidence map represents a measure of how reliable the depth image data is. The higher the value, i.e., the brighter the pixel, the more reliable the measurement.



Note that you cannot enable/disable individual image components in the feature pane. The reason is, that the ToF viewer requires all image components to render the different image window types. Therefore, it enables all image components by default.

For more detailed information about using the ToF Viewer, see the ToF Viewer online help.

Saving Depth and Image Data

All components of an image can be saved in separate files in a variety of formats. This may be useful if you want to view the data in a different tool, i.e., point cloud data in a point cloud processing tool, or if you want to share an image with others, i.e., the range map as a .png file.

Range maps (color and gray values versions), intensity images, and confidence maps can be saved as .png and .tiff files.

Point clouds (color and intensity versions) can be saved as .pcd and .ply files.

For instructions how to save data, see the **Saving Depth and Image Data** topic in the ToF Viewer online help.

8.4.2 Viewing Image Components in the pylon Viewer (ToF)

With default settings, range data in the Coord3D_C16 pixel format are generated. To enable the other image components, use the **Component Selector** and **Component Enable** parameters.

Because the pylon Viewer (ToF) can only display one component at a time, it follows the order mentioned above. If all components are enabled, the range map will be shown. Consequently, if you want to display a part from lower down the list, you have to disable the preceding components first.

To illustrate this, the following procedure shows you how to view the intensity image.

To view the intensity image:

1. In the **Component Selector** drop-down box, choose **Range**.
2. If the **Component Enable** check box is selected, deselect it.
3. In the **Component Selector** drop-down box, choose **Intensity**.

The image display area now shows the intensity image.

If you want to display the confidence map, the range map and the intensity image need to be disabled.

8.5 Image Quality

In the **Image Quality Control** group, there are a number of parameters with which you can improve the visualization and the quality of the point cloud data that the camera generates.

- **Confidence Threshold**

Pixels have to exceed the confidence value specified here in order to be taken into account for the distance measurement. The threshold value is based on the gray values of the confidence map.

- **Spatial Filter**

This filter uses the values of neighboring pixels to filter out spatial noise in an image, based on the raw image data from the sensor (gray values). This helps to flatten bumps in planes and create smoother surfaces. Object edges are left intact. It affects the confidence and intensity components, too.

If you want to use the range filter, you need to enable the spatial filter.

- **Temporal Filter**

This filter uses the values of the same pixel at different points in time to filter out temporal noise in an image, based on the raw image data from the sensor (gray values). This takes into account the motion in a target scene and helps to reduce motion artifacts.

Use the **Strength** parameter (see below) to define how far back the memory of the temporal filter reaches. It affects the confidence and intensity components, too.

- **Strength**

This defines how far back the memory of the temporal filter reaches. The higher the value, the further back.

- **Outlier Tolerance**

This defines by how much a pixel's depth (measured in gray values of the range map) is allowed to differ from that of its neighboring pixels. Outliers will be classed as invalid. As a result, the pixel value will be zero in the range map and the coordinates in the point cloud will be set to NaN. A low value means that less variation is allowed between the pixels' gray values. Therefore, the lower the value, the more aggressive this filter.

- **Range Filter**

This filter operates on the depth information calculated from neighboring pixels to filter out noise in the range data. The spatial filter has to be enabled, too, for the range filter to work.

8.6 Calculating Distance from the Range Map

8.6.1 Monochrome Range Map

The Mono 16 range map contains depth information for each pixel expressed as a gray value. To calculate the distance from these pixel values, use the following formula.

$$\text{Distance Measured [mm]} = \text{DepthMin_parameter} + (\text{Pixel_Value} \times (\text{DepthMax_Parameter} - \text{DepthMin_parameter})) / 65535$$

Pixel_Value stands for the value from the Coord3D_C16 range map.



Distance and Z Coordinate

The distance calculated using the formula above is the actual distance the light travels. The formula will not give you the Z coordinate value. This is because the camera's origin of measurement is the center of the sensor.

To illustrate this, imagine the camera looking at a flat white wall. Light reflected from the edges of the wall has a greater distance to travel than light reflected by a point directly opposite the sensor, i.e., the distances vary while the z value is the same. As a result, the gray value profile produced by such a measurement will have a bowl-like shape.

8.6.2 Color Range Map

You can convert 16-bit range data to RGB data (8 bits per channel). This can be useful for improved visualization of the data.

If you want to determine the distances from the pixel values, Basler recommends using the Mono 16 range map as this procedure is far simpler. For more information, see Section 8.6.1 on [page 56](#).

To convert 16-bit range data to RGB data:

1. The depth value is mapped to a 10-bit value, where 0 equals minDepth and 1023 equals maxDepth.
2. This 10-bit depth value is mapped to 4 color ranges where each range has a resolution of 8 bits.

Depth Value	Mapped to Color Range
0..255	red to yellow (255,0,0) -> (255,255,0)
256..511	yellow to green (255,255,0) -> (0, 255, 0)
512..767	green to aqua (0,255,0) -> (0,255,255)
768..1023	aqua to blue (0,255,255) -> (0, 0, 255)

An efficient way to perform this mapping from 16-bit range data to RGB data is this algorithm:

```
double scale = UINT16_MAX / ( maxDepth - minDepth );
uint32_t d32 = ( depth - minDepth ) * scale;
uint16_t d16 = d32 > UINT16_MAX ? UINT16_MAX : (uint16_t) d32;
```

```
uint16_t val = d16 >> 6 & 0xff;
uint16_t sel = d16 >> 14;
```

```
uint32_t res = val << 8 | 0xff;
```

```
if (sel & 0x01)
```

```
    res = (~res) >> 8 & 0xffff;
```

```
if (sel & 0x02)
```

```
    res = res << 8;
```

```
uint8_t red = res & 0xff;
```

```
res = res >> 8;
```

```
uint8_t green = res & 0xff;
```

```
res = res >> 8;
```

```
blue = res & 0xff;
```

8.6.3 Calculating 3D Coordinates from 2D Range Map

When rectification is enabled, the 2D range map (monochrome or color) gives you the Z coordinate instead of the radial distance value. This means a wall parallel to the sensor plane will deliver constant values, whereas a radial distance value increases the further you are away from the center pixel. The Z coordinate is a dimensionless quantity, or bare number.

You can use the Z coordinate to calculate the 3D coordinates (in mm) from the 2D range map. For this, rectification has to be enabled.

The following parameter values are required for the calculation:

Parameter	Symbol
Minimum Depth	D_{min}
Maximum Depth	D_{max}
Focal Length	f
Center X	c_x
Center Y	c_y

Table 8: Conversion Parameters

To calculate the 3D coordinates, use the following formula, where:

z = range value of a pixel at u,v in the 2D range map

$$Z = \frac{z}{0xffff} \cdot (D_{max} - D_{min}) + D_{min}$$

$$X = \frac{u - c_x}{f} \cdot Z$$

$$Y = \frac{v - c_y}{f} \cdot Z$$

Fig. 20: Formula for Calculating 3D Coordinates from 2D Range Map

The following figure serves to illustrate the conversion. The origin O of the coordinate system is the center of the optical system. This is where the rectified image coordinates differ from the point cloud coordinates as the point cloud's point of the reference is the camera housing. For more details on this, see Section 3.3 on [page 8](#).

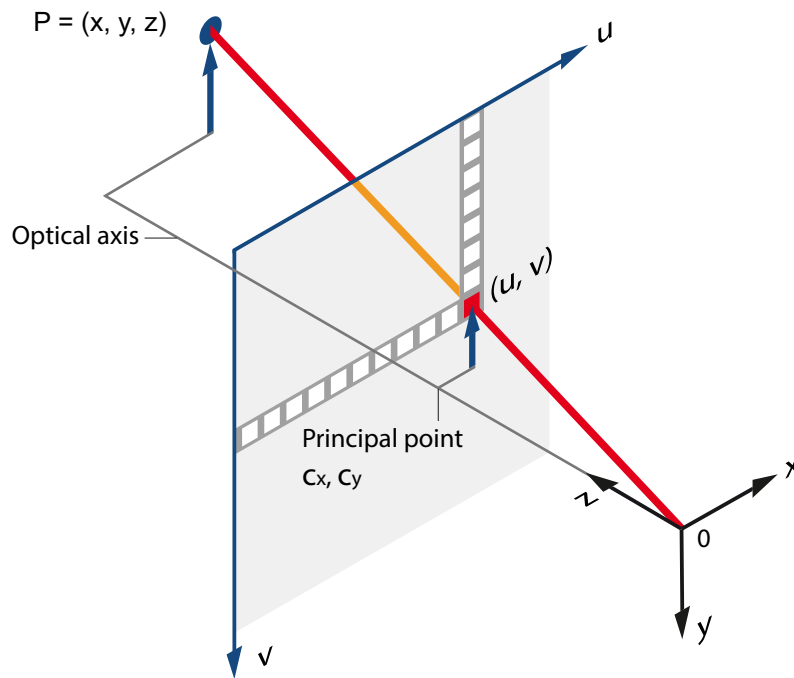


Fig. 21: Coordinate System

8.7 Saving Camera Settings

Any changes you make to the default settings of the camera will be lost when you disconnect the camera, e.g., by disconnecting it from power and/or the computer or by closing the connection in the ToF Viewer or using the API. The only exception to this is the PTP feature. For more information about this, see note on [page 60](#).

If you want to keep your settings for later use, the ToF Viewer offers the option to save them in a .pfs file. This may also be useful in order to save time when configuring other ToF cameras by importing the .pfs file. This means that you don't have to configure the cameras manually.

To save camera settings in a .pfs file:

1. Make the desired changes.
2. Stop image acquisition.
3. In the menu bar, click **File > Save Depth and Image Data**.
4. In the **Save Data** dialog that opens, select the **Current Device Settings** option.

5. In the Base File Name field, specify a common base for the files you save.
The **Base File Name** field accepts variables. Currently, these are {ModelName} and {SerialNumber} which will be replaced the camera's model name and serial number.
6. In the **Folder** field, specify the location where you want to save the file.
7. Select **Append Sequential Number**, if you want to number your files by adding a sequential number to the file name.
8. Click **Save**.
The .pfs file is created and saved in the location you have specified.
The **Save Data** dialog stays open until you close it.

To load camera settings from a .pfs file:

1. In the menu bar, click **Camera > Load Features**.
2. In the Load File dialog, navigate to where you saved the .pfs file and select it.
3. Click **Open**.

The parameters in the ToF Viewer will be populate with the settings saved in the .pfs file.

A .pfs file can be used by your application to configure a camera. Refer to the ParametrizeFromFile C++ sample for details how the settings stored in a .pfs file can be applied by your application.



PTP Remains Enabled After Camera is Disconnected

From Basler ToF Driver 1.3 onwards, the PTP feature remains enabled when the connection to a camera is re-established (i.e., by disconnecting/connecting it in the ToF Viewer or with CToFCamera::Close()/CToFCamera::Open() when using the API). That means that once camera clocks are synchronized using PTP, the camera clocks stay synchronized until a power cycle is performed.

8.8 Managing Performance when Triggering Cameras Simultaneously

If you are triggering image acquisition simultaneously on multiple cameras, the resulting transmission of several images at the same time may cause congestion in your network. This in turn may lead to data packets being dropped.

There are two parameters available which can alleviate the problem:

- **Frame Transmission Delay**
This parameter allows you to stagger the start of image data transmission from each camera. It sets a delay in ticks between when a camera would normally begin transmitting an acquired frame and when it actually begins transmission. (When PTP is enabled, a tick is 1 ns.)
- **Inter-Packet Delay**
If you have the impression that your network hardware can't handle the incoming packet rate, it may help to increase the delay between packet transmissions. This may reduce the amount of dropped packets. Note that this also slows the data transmission. As a result, the camera's frame rate may decrease.

9 Features

9.1 Multichannel

As explained in Section 6.2.1 on [page 35](#), the quality of the distance measurement to a large extent depends on the amount of additional light that hits the sensor. For example, this can be sunlight or light sent out by another camera. As a result, using two or more cameras simultaneously would be problematic.

To enable you to use multiple cameras to capture the same scene, Basler ToF cameras are equipped with four different channels. Each channel sends out light pulses with a specified, unique pattern. This means that you can operate four cameras simultaneously without them interfering with each other.

Even though these light pulses are a form of (undesirable) additional light, they don't lead to an increase in the systematic measurement error. Instead, due to the differences in pulse patterns, the overall ambient light is increased, the effect of which can be compared to placing a halogen lamp in the scene that is switched on and off at random.

Be aware, that this increase in ambient light in turn will lead to an increase in noise in the image and a drop in the signal-to-noise ratio.

To change the channel of a camera:

1. Open the camera.
2. In the **Features** tree, open the **Device Control** group and set the **Device Channel** parameter to a channel that is not in use by any other camera in your multi-camera setup.

Another way to simultaneously run two or more Basler ToF cameras is to use the synchronous free run feature. For information about this, see Section 9.4 on [page 71](#).

9.2 Processing Modes

The Basler ToF camera offers two processing modes:

- HDR (default)
- Standard

The HDR processing mode addresses a problem inherent in time-of-flight technology where, generally speaking, it is difficult to accurately measure the distance of dark objects far away from

the sensor and bright objects close to the camera. The former lead to undersaturated pixels, while the latter lead to oversaturated pixels both of which will result in incorrect measurements.

Major factors in this phenomenon are the reflectivity of objects as well as their distance from the sensor. For more information about this, see Section 6.2.5 on [page 40](#).

From this it follows that if you have dark and bright objects in the same scene, it is difficult to find an exposure time at which both types of object are illuminated adequately.

To combat this, the HDR processing mode offers two different exposure times which will help to achieve a more uniform brightness across the whole image:

- a shorter exposure time for ensuring optimum illumination at close range (default setting 4 ms)
- a longer exposure time for ensuring optimum illumination in the distance (default setting 20 ms)

The results of both these exposures are combined in the following manner:

- data from the long exposure is used for distant objects
- where pixels are saturated, data from the short exposure time is used

The following diagrams illustrate the two processing modes.

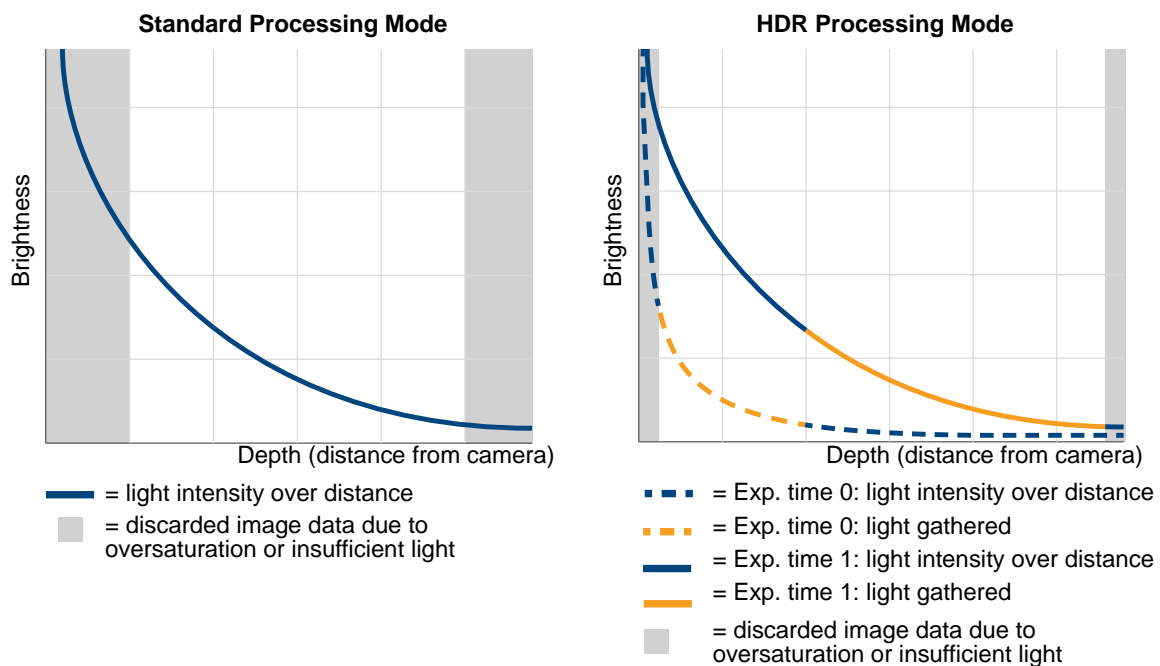


Fig. 22: Discarded Data and Decrease in Brightness over Distance in Standard and HDR Processing Modes



Effects of HDR processing on image components

- Range map
In the area where the information from exposure 0 and exposure 1 is stitched together, a slight increase in noise is noticeable.
- Intensity image
As in the range map, a slight increase in noise is noticeable where the information from exposure 0 and exposure 1 is stitched together.
- Confidence map
In the area where the information from exposure 0 and exposure 1 is stitched together, an increase in the confidence value is noticeable.

9.3 Precision Time Protocol (IEEE 1588)

The Precision Time Protocol (PTP) provides a method to synchronize multiple GigE cameras operated in the same network. It achieves clock accuracy in the sub-microsecond range.

The protocol is defined in the IEEE 1588 standard. Basler ToF Cameras support the revised version of the standard (IEEE 1588-2008, also known as PTP Version 2).

PTP enables a camera to capture images in synchronous free run. For more information, see Section 9.4 on [page 71](#).

Every time the camera is restarted, PTP is disabled. If you want to use PTP, you have to enable it (see Section 9.3.1 on [page 67](#)).

When working with PTP, you may find the SyncFreerun sample helpful. It is included in the Basler ToF Driver package.

Clock Synchronization in a Network via PTP

Through PTP, multiple cameras are automatically synchronized with the most accurate clock found in a network, the so-called master clock or best master clock.

The protocol enables systems within a network to do the following:

- **Synchronize** a local clock with the master clock, i.e., to set the local clock as precisely as possible to the time of the master clock.
- **Syntonize** a local clock with a master clock, i.e., to adjust the frequency of the local clock to the frequency of the master clock. The duration of a second is as identical as possible on both devices.

There are two different methods of finding the master clock:

- A. The synchronization between the different device clocks will determine a clock within one of the cameras to be the best master clock.
- B. A clock outside of a set of cameras will be determined as the master clock; i.e. an external device (e.g. a GPS device) will be the best master clock.

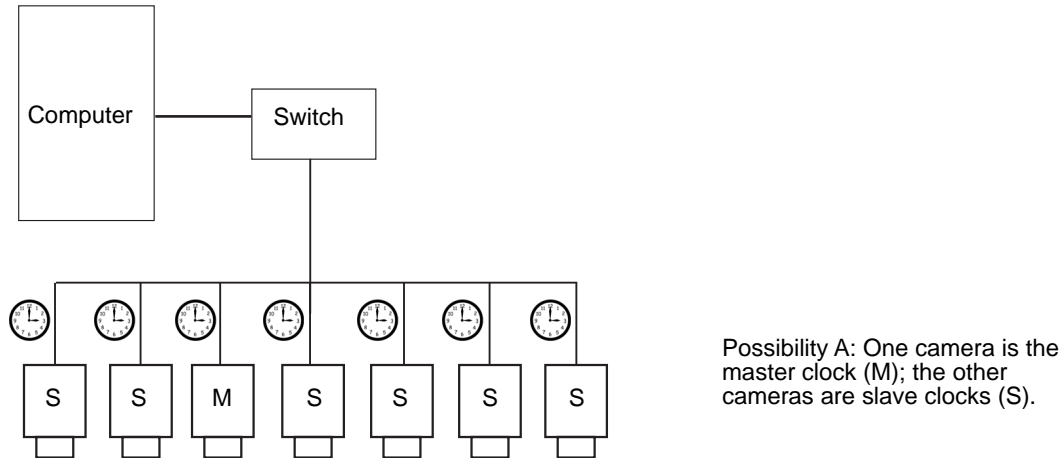


Fig. 23: PTP-capable Cameras Using the Same System Time

How Does PTP Clock Synchronization Work?

The IEEE 1588 standard defines a Best Master Clock (BMC) algorithm in which each clock in a network identifies the most accurate clock and labels it "master clock". All other "slave clocks" synchronize and syntonize with this master.

The basic concept of IEEE 1588 is the exchange of timestamp messages. The protocol defines several periodic messages that trigger a clock to capture a timestamp and communicate timestamp information between the master and slave clocks. This method of using timestamps enables each slave clock in a network to analyze the master clock's timestamp and the network propagation delay. This allows the slave clock to determine the delta from the master in its synchronization algorithm. For details about PTP messages, see the note below.

IEEE 1588 defines 80-bit timestamps for storing and transporting time information. As GigE Vision uses 64-bit timestamps, the PTP timestamps are mapped to the 64-bit timestamps of GigE Vision.

An IEEE 1588-enabled device that operates in a network with no other such devices will not discipline its local clock. The drift and precision of the local clock is identical to a non-IEEE 1588-enabled device.

If no device in a network of IEEE 1588-enabled devices has a time traceable to the Universal Time Coordinated (UTC), the network will operate in the arbitrary timescale mode (ARB). In this mode, the epoch is arbitrary, as it is not bound to an absolute time. This timescale is relative, i.e., it is only valid in the network. The best master clock algorithm will select the clock which has the highest stability and precision as the master clock of the network.



Details about PTP Messages

In standard Ethernet frames, four IEEE 1588 messages are included (see [Figure 24](#)): Sync, Follow_up, Delay_Req, Delay_Resp

The Basler ToF cameras are configured to use the end-to-end delay measurement mechanism, i.e., the request-response delay mechanism.

The Sync, Delay_Req, Follow_Up, and Delay_Resp messages are used to generate and communicate the timing information needed to synchronize the clocks using the delay request-response mechanism.

In order for a slave clock to synchronize with a master clock, the slave must know two pieces of information:

1. How much is the slave's clock off from the master clock?
This is determined by the Sync and Follow_up message pair.
2. What is the network propagation delay?
This is determined by the Delay_Req and Delay_Resp pair.

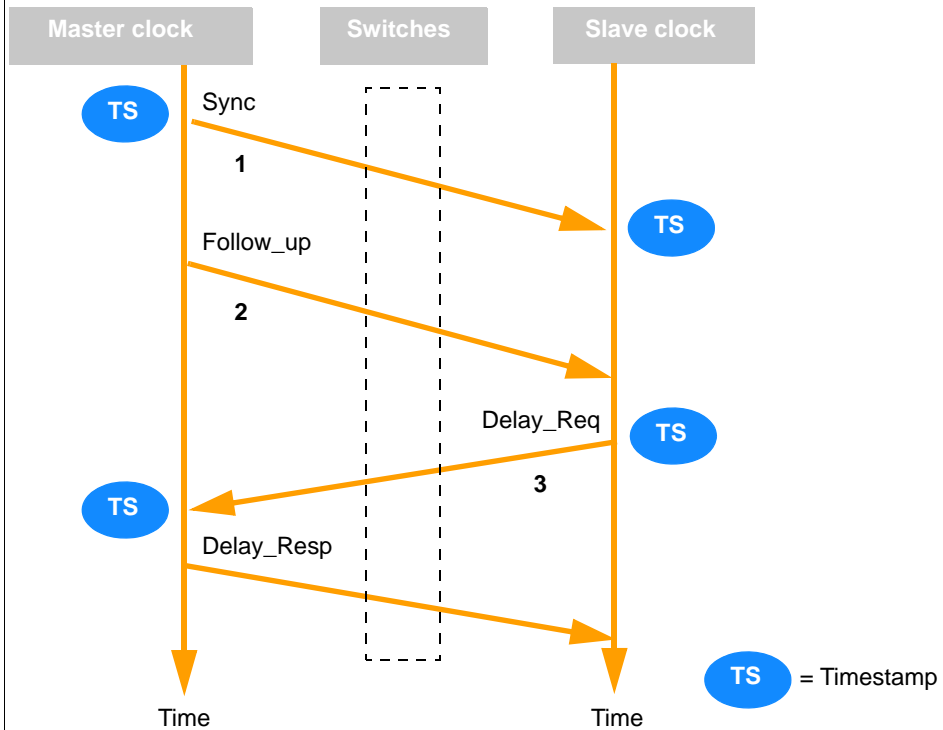


Fig. 24: PTP Clock Synchronization: Message Exchange Sequence

The "delay request" message is received and timestamped by the master clock, and the arrival timestamp is sent back to the slave clock in a "delay response" packet. The difference between these two timestamps is the network propagation delay.

By sending and receiving these synchronization packets, the slave clocks can accurately measure the offset between their local clock and the master clock. The slaves can then adjust their clocks by this offset to match the time of the master.

9.3.1 Enabling PTP Clock Synchronization

If you want to synchronize cameras using the Precision Time Protocol, you must enable PTP clock synchronization. In the default factory setup, PTP clock synchronization is disabled.



Once PTP is enabled, it stays enabled until a camera is power cycled or the feature is disabled. Just closing the connection to the camera (in the ToF Viewer or using the API), doesn't reset its status.

To enable PTP clock synchronization:

1. If you've decided to use an external device as master clock (e.g. a GPS device or a software application on a computer synchronized by NTP), configure the external device:

Basler recommends an ANNOUNCE interval of 2 seconds and a SYNC interval of 0.5 seconds.

2. Make sure that the following conditions are met:

- All cameras on which you want to use PTP are configured in the same network segment.
- All cameras support PTP.

You can check whether a camera supports PTP via the following command:

```
CBooleanPtr ptrIEEE1588Enable = camera.GetParameter("GevIEEE1588");
if ( IsWritable(ptrIEEE1588Enable) )
{
    // ...
}
```

3. (Optional) If you want to synchronize more than eight cameras, see the following note.



Switch with PTP Support Recommended

If you want to synchronize more than eight GigE cameras operated in the same network, Basler recommends the following:

- Use a switch with PTP support.
- Configure the switch in the two-step boundary mode.

It is possible that the switch's clock will always be the master clock and that no camera clock reaches the master state. The reason is that the decision is based on a data set used by the BMC algorithm (best master clock).

If this situation occurs, Basler recommends the following:

Make sure that Priority 1 in the switch settings is set to a value >128 (e.g., 129 or higher). This priority setting ensures that a PTP port is able to be in the slave state and a connected camera is able to become a master.

4. For **all cameras** that you want to synchronize, enable PTP clock synchronization:

In the **Transport Layer Control** group, select the **IEEE 1588 V2 Enabled** check box.

What happens next depends on your setup:

- **An external device serves as the master clock:**

As soon as PTP is enabled, the master clock starts sending and receiving synchronization packets so that the slave clocks can synchronize their time with the master clock. This will take a moment (approximately a few seconds or minutes depending on the number of PTP devices involved).

From now on, the master and slave clocks are continuously synchronizing.

- **One of the cameras serves as the master clock:**

As soon as PTP is enabled for all camera clocks, the cameras start sending and receiving synchronization packets and determine the slave clocks and the best master clock. This will take a moment (approximately a few seconds or minutes depending on the number of PTP devices involved).

Once a master clock has been determined, the slaves can adjust their clocks to match the time of the master. From now on, the master and slave clocks are continuously synchronizing.

9.3.2 Checking the Status of the PTP Clock Synchronization

After PTP clock synchronization has been enabled on all devices (see Section 9.3.1 on [page 67](#)), you can check the status of the synchronization.

Status Parameters

Four parameter values can be read from each device to determine the status of the PTP clock synchronization:

- **IEEE 1588 Offset From Master:** A 32-bit number. Indicates the temporal offset between the master clock and the clock of the current IEEE 1588 device in nanoseconds.
- **IEEE 1588 Clock ID:** A 64-bit number. Indicates the unique ID of the current IEEE 1588 device (the "clock ID").
- **IEEE 1588 Parent Clock ID:** A 64-bit number. Indicates the clock ID of the IEEE 1588 device that currently serves as the master clock (the "parent clock ID").
- **IEEE 1588 Status Latched:** An enumeration. Indicates the state of the current IEEE 1588 device, e.g. whether it is a master or a slave clock. The returned values match the IEEE 1588 PTP port state enumeration (Initializing, Faulty, Disabled, Listening, Pre_Master, Master, Passive, Uncalibrated, and Slave). For more information, refer to the pylon API documentation and the IEEE 1588 specification.

The parameter values can be used to do the following:

- Delay image acquisition until all cameras are properly synchronized, i.e. until the master and slave clocks have been determined and the temporal offset between the master clock and the slave clocks is low enough for your needs.
- Optimize your network setup for high clock accuracy. For example, you can compare the temporal offsets of the IEEE 1588 devices while changing the network hardware, e.g., routers or switches.

Before the parameter values can be read, you must click **Execute** for the **IEEE 1588 Data Set Latch** parameter to take a "snapshot" (also known as the "latched data set") of the camera's current PTP clock synchronization status. This ensures that all parameter values relate to exactly the same point in time.

The snapshot includes all four status parameter values: **IEEE 1588 Offset From Master**, **IEEE 1588 Clock ID**, **IEEE 1588 Parent Clock ID**, and **IEEE 1588 Status Latched**. The values will not change until you execute **IEEE 1588 Data Set Latch** on this device again.



Instead of reading **IEEE 1588 Status Latched**, you can read the equivalent **IEEE 1588 Status** parameter value from the device. This parameter value also provides the periodically updated IEEE 1588 device status, but does not require executing the **IEEE 1588 Data Set Latch** command beforehand.

Note, however, that if you read multiple IEEE 1588-related values from a device, the **IEEE 1588 Status** parameter value will not relate to the same point in time as the other values.

To check the status of the PTP clock synchronization:

1. Make sure that PTP clock synchronization has been enabled on all devices (see Section 9.3.1 on [page 67](#)).

For **all cameras** whose status you want to check, perform the following steps:

2. Click **Execute** for the **IEEE 1588 Data Set Latch** parameter to take a snapshot of the camera's current PTP clock synchronization status.
3. Read one or more of the following parameter values from the device:
 - **IEEE 1588 Offset From Master**
 - **IEEE 1588 Clock ID**
 - **IEEE 1588 Parent Clock ID**
 - **IEEE 1588 Status Latched**

All of these parameter values relate to exactly the same point in time, i.e., when the device received the **IEEE 1588 Data Set Latch** command.

9.3.3 How to Check When a Camera is Synchronized to a Master

To check when a camera is synchronized to a master:

1. For **all cameras** that you want to synchronize, enable PTP clock synchronization. In the **Transport Layer Control** parameter group, select the **IEEE 1588 V2 Enabled** check box.

The state of the **IEEE 1588 Status** parameter switches to **Slave**. Then, synchronization and syntonization take place. The value of the clock and the clock speed are continuously adjusted.

2. Click **Execute** for the **IEEE 1588 Data Set Latch** parameter to get information about the IEEE 1588 data set.

In particular, the following two values are important:

- **IEEE 1588 Status Latched:** This value shows the PTP state for the point in time when the data set was latched (Initializing, Faulty, Disabled, Listening, Pre_Master, Master, Passive, Uncalibrated, or Slave).
- **IEEE 1588 Offset From Master:** This value shows the offset from the master clock for the point in time when the data set was latched.

The offset from master is related to the precision of the synchronization: the smaller the absolute value of the offset from master, the higher the precision. Due to the fact that the clock is adjusted continuously by a control system, the offset will be oscillating continuously around the master value. With time progressing, the amplitudes of these oscillations will get smaller, though.

[Figure 25](#) shows how the offset from master value changes over time. The time window is represented by a red rectangle. The smaller the absolute value of the offset from the master, the higher the precision.

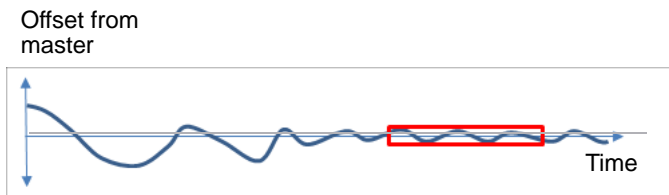


Fig. 25: Evaluation of OffsetFromMaster Values Tracked Over Time

3. In order to find the correct point in time where you can be sure that the maximum absolute offset from master is below a certain threshold (defined by you), use the SyncFreerun sample included in the Basler ToF Driver package.

Once the check for camera synchronization has been completed successfully, the check doesn't need to be repeated until one of the following events occurs:

- one or more cameras are power cycled
- a PTP-capable device is added to or removed from the network
- PTP is disabled on one or more cameras

9.4 Synchronous Free Run

Using PTP, it is possible to let a group of cameras capture images in synchronous free run, meaning that the images captured by the individual cameras are taken at exactly the same point in time (see [Figure 26](#)). Due to the problems with ambient light described in [Section 6.2.1](#) on [page 35](#), this is not desirable for Basler ToF cameras.

However, you can use PTP to accurately time the exposures of several cameras so that the light of one camera doesn't interfere with the other cameras' measurements (see [Figure 27](#)). In this scenario, the exposures start in precisely time-aligned intervals and in chronological order.

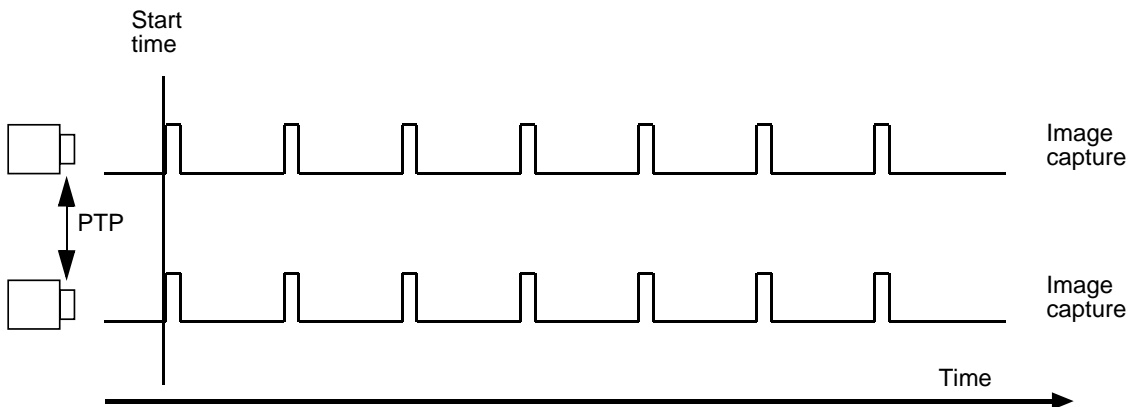


Fig. 26: Image Capture With PTP – Not Desirable When Using Basler ToF Cameras

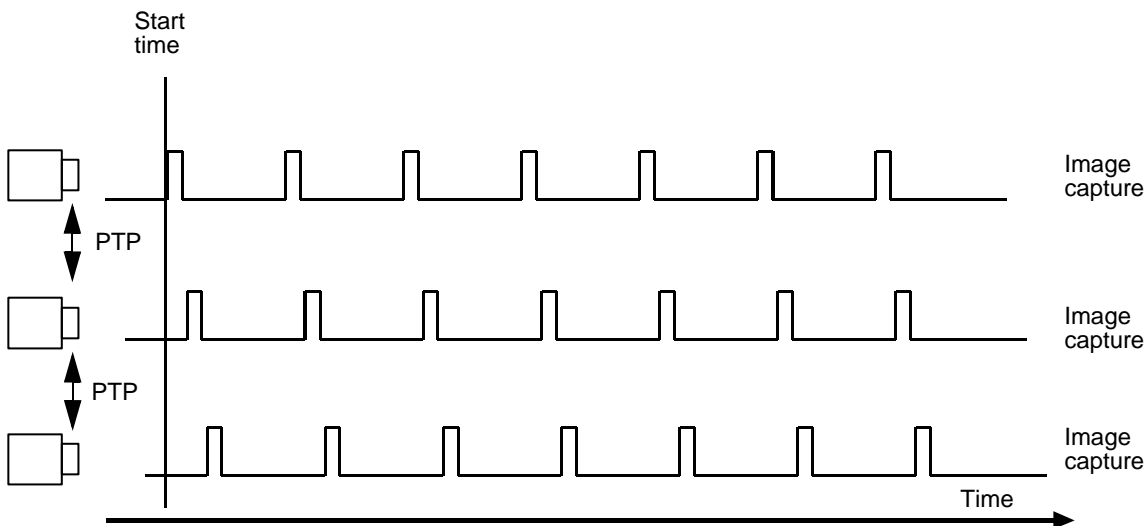


Fig. 27: Image Capture With PTP and Synchronous Free Run Ensuring that Exposures Happen Consecutively

For more information about the PTP feature, see [Section 9.3](#) on [page 64](#). You may also find the `SyncFreerun` sample helpful which is included in the Basler ToF Driver package.

Teaming a Basler ToF Camera with a 2D Camera

There is one use case where you may want exposures to happen simultaneously as shown in [Figure 26](#), and that is when you team a Basler ToF camera with a 2D camera. As the 2D camera doesn't have its own light source, it won't interfere with the ToF camera's measurement.

Note that the near-infrared light of the ToF camera may interfere with the 2D camera. If you use a camera without an IR cut filter, you may see flashes of light in the captured images. Therefore, using a camera with an IR cut filter is the safest option.

9.4.1 Synchronous Free Run Parameters

The main parameters associated with the synchronous free run feature are:

- **Sync Timer**

Enables or disables the synchronous free run feature. Available in the **Trigger Source** drop-down box.

- **Start Time Low** and **Start Time High**

These two 32-bit values represent the lower and the higher part of a 64-bit GigE Vision timestamp (in nanoseconds). Available under **Acquisition Control > Sync Timer Control**.

Both parameters combined determine the start time for the synchronous free run feature.

- If zero (0) is entered or if the start time is set to a point of time in the past, the free run starts at the next possible point in time.
- If the start time is set to a point in time in the future, the free run starts at the specified time.

To check the current timestamp of the camera, click **Execute** for the **Timestamp Latch** parameter to take a "snapshot" of the camera's current time settings. After that, you can read the values of the **Timestamp Low** and **Timestamp High** parameters to determine the timestamp value of the snapshot.

- **Trigger Rate**

Determines the rate at which the camera is triggering image acquisition (in frames per second). Available under **Acquisition Control > Sync Timer Control**.

- **Update**

Each time you change one or more of the **Start Time Low**, **Start Time High**, or **Trigger Rate** parameters, you must execute the **Update** command to apply the changes. The update command ensures that all settings are applied at the same time. Available under **Acquisition Control > Sync Timer Control**.

9.4.2 Using Synchronous Free Run

To configure the synchronous free run of multiple Basler ToF cameras:

1. Before configuring the synchronous free run of multiple cameras, make sure that the following conditions are met:
 - All cameras you want to trigger synchronously via the synchronous free run feature must be configured in the same network segment.
 - PTP has been implemented and enabled on all cameras. All camera clocks run synchronously.

For more information about enabling PTP, see Section 9.3 on [page 64](#).

On **all cameras** that you want to run in synchronized free run, configure the following settings:

2. Set the **Trigger Mode** parameter to **On**.
3. Set the **Trigger Source** parameter to **Sync Timer**.
4. Set the synchronous free run parameters in the **Sync Timer Control** group:
 - a. Set the **Start Time Low** and **Start Time High** parameters to zero (0).
 - b. Verify the maximum possible frame rate the camera can manage.
 - c. Set the **Trigger Rate** to the desired value. Example: If you want to acquire 10 frames per second, set the **Trigger Rate** parameter to 10.
 - d. Make sure that you do not overtrigger the camera. If you overtrigger the camera, frame triggers may be ignored.
 - e. Execute the **Update** command so that the complete start time (i.e., the low and high portion) and the frame rate are adopted by the camera.

As soon as the start time for the synchronous free run is reached, the camera starts acquiring images continuously.



Triggering multiple cameras simultaneously may cause network congestion and lead to data packets being dropped. To find out how to prevent this, see Section 8.8 on [page 61](#).

9.5 Binning

The binning feature allows you to improve the signal-to-noise ratio. This is achieved by averaging the values of 2 x 2 neighboring pixels. This means that in effect only 1 value will need to be transmitted instead of 4. However, when using binning, image resolution will decrease.

Binning happens after the image data has been processed, i.e., on the range data. The effect of it can be seen in the range map, the intensity image, the confidence map, and the point cloud.

9.6 Rectification

The rectification feature allows you to correct radial lens distortion in the 2D range map. Radial lens distortion is a kind of optical aberration that is common in almost all types of lenses. It leads to changes in magnification in an image across the field of view of the camera. In the case of the Basler ToF Camera, the distortion is in the form of the barrel distortion. Barrel distortion causes a reduction in resolution at the edges of an image.

To counter this effect and remove the distortion, the image pixels are interpolated in such a way that the magnification remains constant across the field of view.

Rectification is enabled by default. The effect of it can be seen in the range map, the intensity image, and the confidence map.

Custom Rectification

If you want to create your own rectification solution, you can use the calibration parameters and radial distortion coefficients supplied by the camera. Rectification has to be **disabled** for this.

Calibration parameters:

- Minimum Depth
- Maximum Depth
- Center X
- Center Y

Radial distortion coefficients:

- K1
- K2

More information on this can be found on the OpenCV website: https://docs.opencv.org/2.4/modules/calib3d/doc/camera_calibration_and_3d_reconstruction.html

Appendix



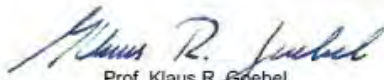
EYE SAFETY CERTIFICATE

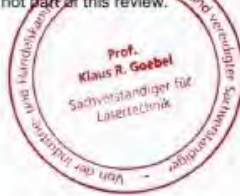
The LED product described below has been classified regarding eye safety according to the stated norms and has been evaluated as described. Measurement techniques and test results are documented in the stated safety report.

LED Safety Report	1610241196 GUT		
Manufacturer / Distributor	Basler AG		
Street	An der Strusbek 60 – 62		
Post Code / Town	Germany – 22926 Ahrensburg		
Product / System			
Name	ToF 640 – 20gm		
Test unit S/N	22012258		
intended use	Modulated infrared lighting for the integrated camera system		
LED – Source(s)			
Manufacturer	OSRAM Opto Semiconductors		
Model & S/N	SFH 4715S (8x)		
LED Type / Wavelength	SMD LED with silicone lens	λ	850 nm \pm 15 nm
Op. Mode / Power	modulated	Φ_e	1030 mW
Norms / Regulations			
ISO IEC EN	62 471:2008		
FDA ANSI	/.		
BG or national	EG RIL: 2006/25/EG // OStrV:2010-07 // TROS-IOS		
Classification			
Operating Mode / Condition Applies to	Normal operation Operator	Set-up/Maintenance	Service / Repair Manufaturer
Satisfies the conditions of class	1	1	2
Eye safety confirmed	Yes	Yes	No
Viewing distance RG0	250 mm		/.
Time limit in seconds	750	750	/.

Our expert's report confirms the classification and safety of the LED system (product) for the operator in the above mentioned operating modes as per the operator's manual data sheet of the manufacturer referred to the original delivery status. A risk analysis was not part of this review.

Darmstadt, 20th, December 2016


 Prof. Klaus R. Goebel
 Öffentlich bestellte und vereidigte Sachverständiger für Lasertechnik der IHK Darmstadt.



• Öffentlich bestellte und vereidigte Sachverständiger für Lasertechnik
 • Beratende Ingenieure der Kammer Hessen / Reg.: B 902



File: 1610241196_zert_e_v1_p.docx
 • Ingenieurbüro Goebel GmbH

Revision History

Doc. ID Number	Date	Changes
AW00133801000	21 Jan 2015	Initial release of this document. Valid for the Basler TOF-PROTO3 functional demonstrator camera described in the <i>Functional Demonstrator Information</i> document (AW001337).
AW00133802000	2 Apr 2015	Added field of view information in Table 1 on page 5 . Added information regarding the pylon Camera Software Suite for Linux in Table 1 on page 5 , Section 3.5 on page 10 , and Section 7.1.2 on page 44 . Corrected Range Z description in Table 3 on page 15 . Added information regarding GenTL for TOF in Table 1 on page 3 , in the note on page 5 , and in Section 3.1.2 on page 10 . Added an index on page 79 .
AW00133803000	23 Sep 2015	Re-organized document structure. Updated cover photo. Updated technical drawings in Section 3.2 on page 7 . Added Chapter 4 on page 15 . Updated Windows and Linux installation procedures in Section 7.1 on page 42 . Added Chapter 6 on page 32 . Added Chapter 8 on page 38 .
AW00133804000	17 Mar 2016	Minor changes and clarifications throughout the manual. Updated camera dimensions in Figure 1 on page 7 . Updated information in Section 6.1.1 on page 33 and added Figure 14 on page 34 . Deleted previous chapters 7 ("Image Acquisition") and 8 ("Camera Functionality") and moved content to new Chapter 8 on page 47 . Added note in Section 8.2 on page 50 . Added Figure 17 on page 50 . Added Section 8.5 on page 55 . Added information about saving point clouds to file on page 56 . Added Section 8.6 on page 56 .
AW00133805000	12 May 2016	Changed the measurement range to 13.325 m in Table 1 on page 5 . Changed the maximum frame rate to 20 fps in Table 1 on page 5 . Revised Section 6.2.2 on page 35 . Added Figure 6 on page 22 , Figure 14 on page 40 , and Figure 15 on page 48 . Revised Section 6.2.6 on page 41 . Section 8.2 on page 50 . Added "Using the ROI to Reduce Ambiguous Results" on page 50 . Changed the scaling factor to 13325 mm / 65535 in formula on page 56 .

Doc. ID Number	Date	Changes
AW00133806000	7 Oct 2016	<p>Updated specifications in Table 1 on page 5.</p> <p>Changed the measurement range to 13.320 m throughout the manual.</p> <p>Added Section 4.3 on page 19 and Section 4.4 on page 21 (I/O line information).</p> <p>Added Chapter 5 on page 24 (description of how to configure I/O lines).</p> <p>Added information about temperature drift in Section 6.2.3 on page 36.</p> <p>Added figures in Section 6.2.2 on page 35 and Section 6.2.4 on page 39.</p> <p>Updated acquisition control information in Section 8.3 on page 51.</p> <p>Updated image format control information in Section 8.4 on page 52.</p> <p>Updated formula for calculating distance in Section 8.6 on page 56.</p> <p>Added Chapter 9 on page 62 (descriptions of features).</p>
AW00133807000	7 Nov 2016	<p>Added notice about how to avoid switch-on surges in Section 2.2 on page 3.</p> <p>Removed warnings about using powered hubs in Section 2.1 on page 2.</p> <p>Updated code snippets in Chapter 5.</p> <p>Added Figure 17 on page 41.</p> <p>Added ToF Viewer information in Chapter 8.</p> <p>Updated code snippets in Chapter 9.</p> <p>Added Figure 22 on page 63.</p>
AW00133808000	16 Mar 2017	<p>Minor changes throughout the manual.</p> <p>Updated power consumption information in Table 1 on page 5 and Table 2 on page 10.</p> <p>Updated information in Section 4.1.2 on page 17 and Section 4.2.2 on page 17.</p> <p>Updated shield information in Table 3 on page 16.</p> <p>Added the Programmer's Guide to the list of installed components in Section 7.1 on page 42.</p> <p>Updated installation information for Linux operating systems in Section 7.1.2 on page 44.</p> <p>Added information about the orientation of the axes in the coordinate system used by the Basler ToF Camera in Section 8.4 on page 52.</p> <p>Added Figure 19 on page 52.</p> <p>Added information about how 16-bit range data can be converted into RGB data in Section 8.6.2 on page 56.</p> <p>Added eye safety certificate in the Appendix on page 75.</p>
AW00133809000	17 Jul 2017	<p>Moved information about the camera's coordinate system to Section 3.3 on page 8.</p> <p>Updated the spatial filter and temporal filter information in Section 8.5 on page 55.</p> <p>Added the range filter description in Section 8.5 on page 55.</p> <p>Added information about saving camera features in Section 8.7 on page 59.</p> <p>Added information about the binning feature in Section 9.5 on page 73.</p> <p>Added information about the rectification feature in Section 9.6 on page 74.</p>

Doc. ID Number	Date	Changes
AW00133810000	9 Apr 2018	<p>Added information how to report a faulty camera on page 2.</p> <p>Added reference to the Saving Depth and Image Data feature in the note on page 9.</p> <p>Added that cameras can be triggered simultaneously using hardware triggers applied to the input lines in Section 5.1.1 on page 24.</p> <p>Clarified how the measurement result is influenced by the temperature in the "Temperature Drift" section on page 37.</p> <p>Clarified that a low confidence threshold means that more dark pixels will be considered reliable on page 53.</p> <p>Added "Saving Depth and Image Data" section on page 53.</p> <p>Moved the "Calculating 3D Coordinates from 2D Range Map" section to page 58.</p> <p>Updated information how to save camera settings in Section 8.7 on page 59.</p> <p>Added Section 8.8 on page 61 which provides information about how to avoid packet loss when triggering cameras simultaneously.</p> <p>Added notes warning about packet loss when triggering cameras simultaneously on page 24 and page 73.</p> <p>Added information about creating a custom rectification solution on page 74.</p>

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