Basler Engineering Sample ToF

USER'S MANUAL

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1 General Information

The purpose of this document is to familiarize you with the basic capabilities of the Basler Engineering Sample 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

This camera is an engineering sample intended for use in development and test environments.

The camera is only available for a limited period of time (until the end of 2016) and will be produced in small numbers. You should be aware of this before planning to use it in a production environment.

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 which meets the Safety Extra Low Voltage (SELV) and Limited Power Supply (LPS) requirements.
- If you use a powered hub, it also must meet the SELV and LPS requirements.

WARNING

Fire Hazard

Non-approved power supplies may cause fire and burns.

- You must use a camera power supply which meets the Limited Power Supply (LPS) requirements.
- If you use a powered hub, it also must meet the 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 35 cm, the LEDs fall into risk group 0 (no risk).

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

Documentation

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

2.2 Power

NOTICE
Voltage outside of the specified range can damage the camera. If you are supplying camera power via the camera's 12-pin connector and the voltage of the power is greater than 24 VDC (± 5 %), 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.

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 3.6.1 on page 10.

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 certain 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	Engineering Sample ToF
Sensor Size (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)	20 fps
Mono/Color	Mono
Wavelength	850 nm
Non-ambiguity Range	0 m to 13.325 m
Absolute Accuracy and Repeatability	Absolute Accuracy: ± 1 cm * Repeatability (1 σ): 8 mm *
Drift with Temperature	3 mm/1 °C
External Light Disturbance	above 4000 Lux
Communication Interface	Gigabit Ethernet (1000 Mbit/s)
Image Components	▪ Range image ▪ Intensity image ▪ Confidence map
Pixel Formats	▪ Mono16 Available for all image components (Range, Intensity, Confidence) ▪ RGB8 Available for the range image ▪ Coord3D_ABC32f (point cloud) Available for the range image
Synchronization	Free run
Exposure Time Control	Programmable via the camera API, Auto Mode
Camera Power Requirements	24 VDC (± 5 %), supplied via the camera's 12-pin connector

Table 1: General Specifications

Specification	Engineering Sample ToF
Max Power Consumption	max. 15 W @ 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)
Conformity	CE, RoHS, GenICam, GigE Vision, FCC The CE Conformity Declaration is available on the Basler website: www.baslerweb.com
Eye Safety	EN 62471:2008 RG 1
Software	Basler ToF Driver (version 1.0.0 or higher) Available for Windows (x86, x64) and Linux (x86, x64)

Table 1: General Specifications

* Measured under the following conditions: flat white target with over 90 % reflectivity, in a room with zero ambient light at 22 °C, with default settings, exposure time 15 ms, looking at the center of the range image, 8 x 8 pixels over 32 images, in a range from 0.8 m to 4.8 m

For more information about accuracy and repeatability, see Section 5.1.1 on page 19.

3.2 Mechanical Specifications

This section contains information about the dimensions and mounting points of the Basler Engineering Sample ToF camera.

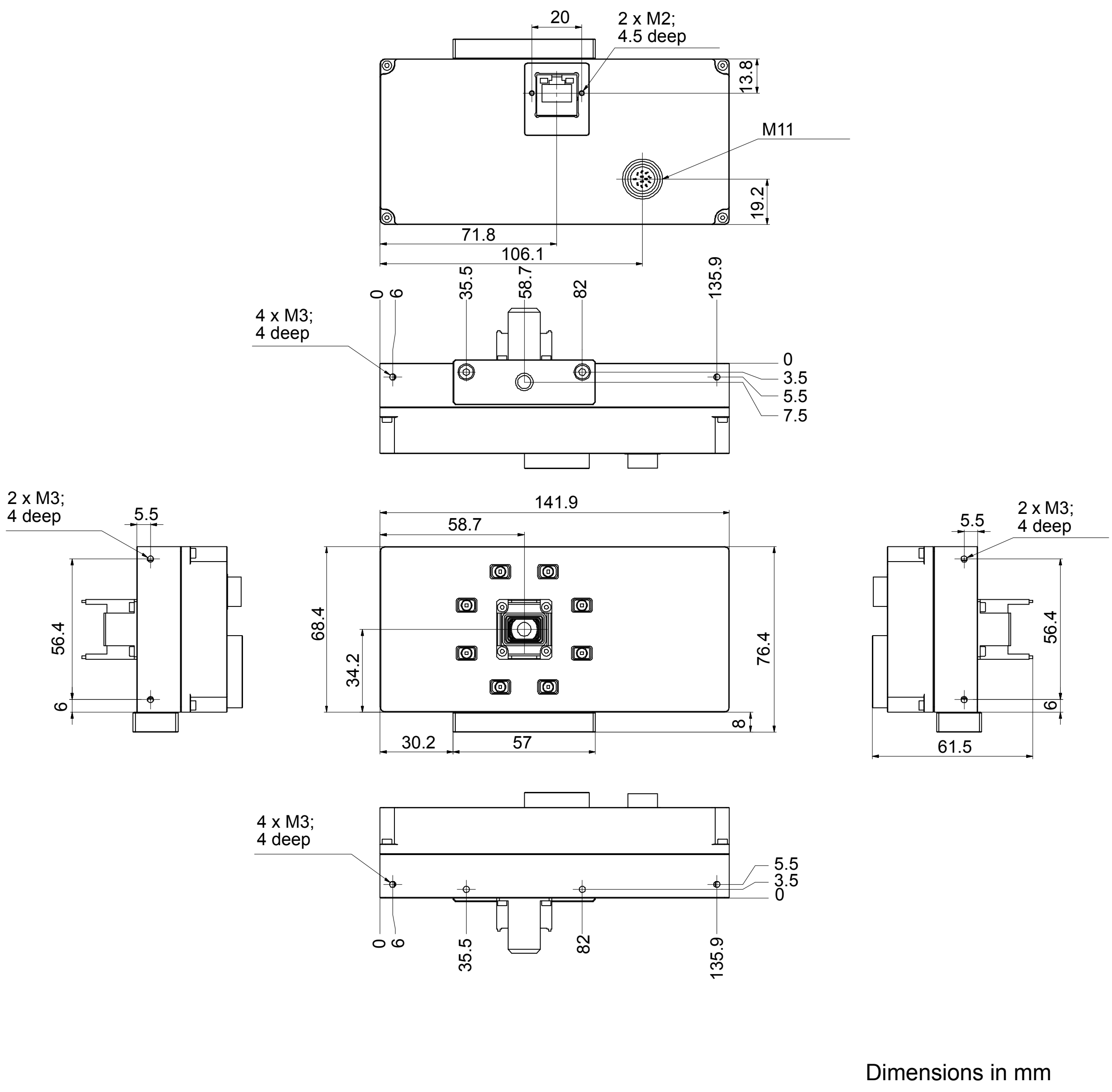


Fig. 1: Camera Dimensions

3.3 Hardware Requirements

- Basler Engineering Sample ToF camera
- Power supply
- GigE cable
- Camera bracket
- PC with the following specifications:
  - Processor: Intel i5 3.3 GHz or better
  - RAM: 4 GB minimum
  - Network adapter: Intel Pro 1000 (recommended)

3.4 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 a GenICam GenTL producer, the pylon Viewer, the pylon IP Configurator as well as sample code.

  You can download the Basler ToF Driver from the Basler website: www.baslerweb.com. Go to **Support** > **Download** > **Software Downloads** > **TOF Software** and choose the required version.

3.5 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 15.

Power Requirements	Power Consumption
+24 VDC (± 5 %)	max. 15 W @ 24 VDC

Table 2: Camera Power

NOTICE

Voltage outside of the specified range can damage the camera.

If you are supplying camera power via the camera's 12-pin connector and the voltage of the power is greater than 24 VDC (± 5 %), 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.

3.6 Environmental Requirements

3.6.1 Temperature and Humidity

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

Influence of Temperature on Camera Performance

- The camera may not deliver reliable distance measurements immediately after having been switched on. For example, after 5 minutes, there may still be a measurement error of 3 to 4 cm. After approx. 20 minutes, the housing temperature should have stabilized and accurate measurements can be taken.
- Measurement accuracy decreases with each degree of change in temperature. Therefore, you should take measures to keep the housing temperature of the camera stable.
- At temperatures above 50 °C, reliable camera operation can't be guaranteed anymore.
- At housing temperatures below 0 °C, the camera won't start.

For more information about the effects of temperature, see Section 5.2.3 on page 21.

3.6.2 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.
- Don't exceed frame rates of 15 fps and exposure times of 25 ms.

3.6.3 Automatic Temperature Control

The Engineering Sample ToF camera is equipped with two temperature sensors that measure the temperature of the LED board and the sensor board respectively. If certain temperatures are reached at which reliable operation of the camera can't be guaranteed anymore, the LED board and the sensor board will be switched off and the pylon Viewer will show 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 3.6.2). When the temperatures have fallen by approx. 10 %, LED and sensor board will come back on and the image acquisition continues.

Temperatures at which the boards switch off:

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

3.7 Software Licensing Information

3.7.1 LWIP TCP/IP Licensing

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

3.7.2 LZ4 Licensing

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

4 Physical Interface

4.1 Camera Connectors

The Engineering Sample ToF camera is equipped with two connectors at the back of its housing as shown in Figure 2:

- 12-pin Connector
- 8-pin RJ45 Jack

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

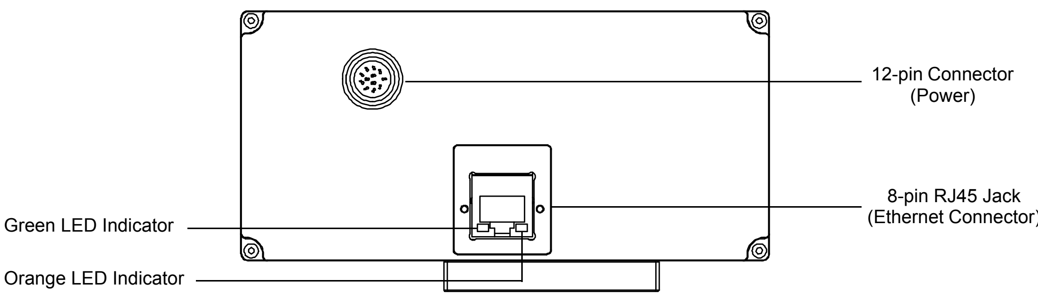


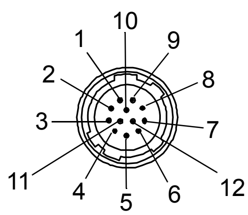
Fig. 2: Camera Connections

4.1.1 12-pin Connector

The 12-pin connector is used to access the two physical input lines and four 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	Designation	Pin	Designation
1	Camera Power Ground *	7	Opto Out 2
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	Opto Out 3
6	Opto Out 1	12	Opto Out 4
		Shield	Shield Ground / PE *** *** Shield Ground is AC-coupled to pins 8 and 9 inside the camera.

Table 3: Connector Pin Assignments and Numbering

* Pins 1 and 2 are tied together inside the camera.

** Pins 8 and 9 are tied together inside the camera.

To avoid a voltage drop when there are long wires between your power supply and the camera, we recommend 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.

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 adhere to 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. Contact your Basler sales representative to order cable assemblies.

Suitable cable assemblies are also available from, for example, Components Express Inc. and from the Intercon 1 division of Nortech Systems, Inc.

To ensure that you order cables with the correct connectors, note the horizontal orientation of the screws before ordering.

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 PC 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 connect power to the camera and to connect to the camera's I/O lines as shown in Figure 3.

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.

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 a cable assembly that is terminated with a 12-pin Hirose plug on one end and unterminated on the other. Contact your Basler sales representative to order connectors or cables.

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.

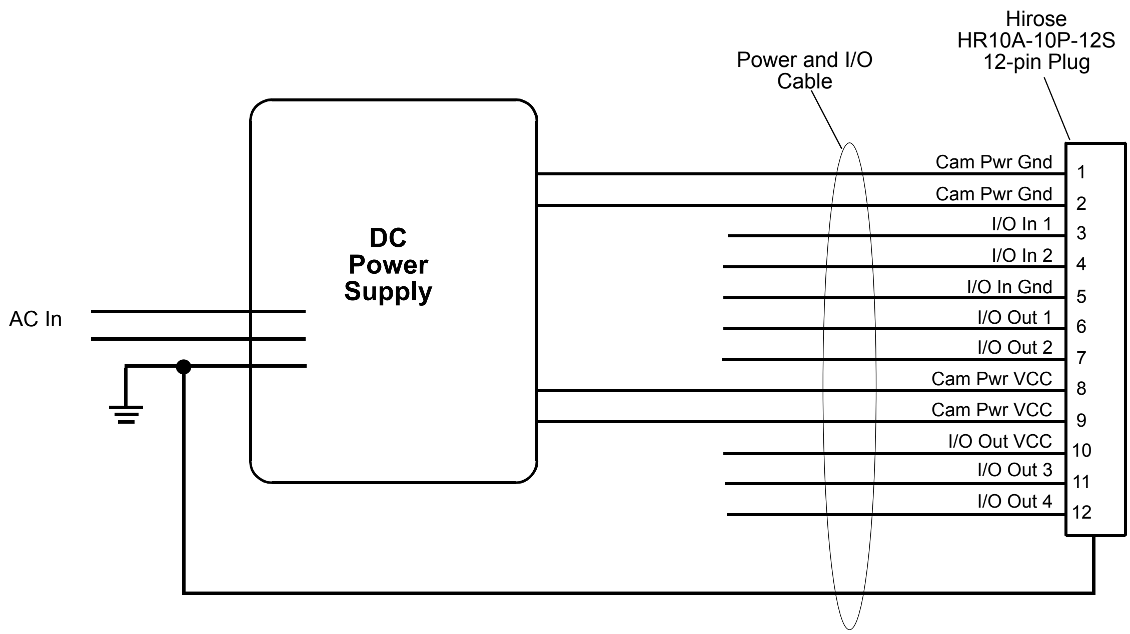


Fig. 3: Power and I/O Cable

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.

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.

5 Time-of-Flight Concepts

Based on the Time-of-Flight (ToF) principle, the Basler Engineering Sample 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.

5.1 Distance Measurement with Basler ToF Cameras

The Engineering Sample 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 4 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

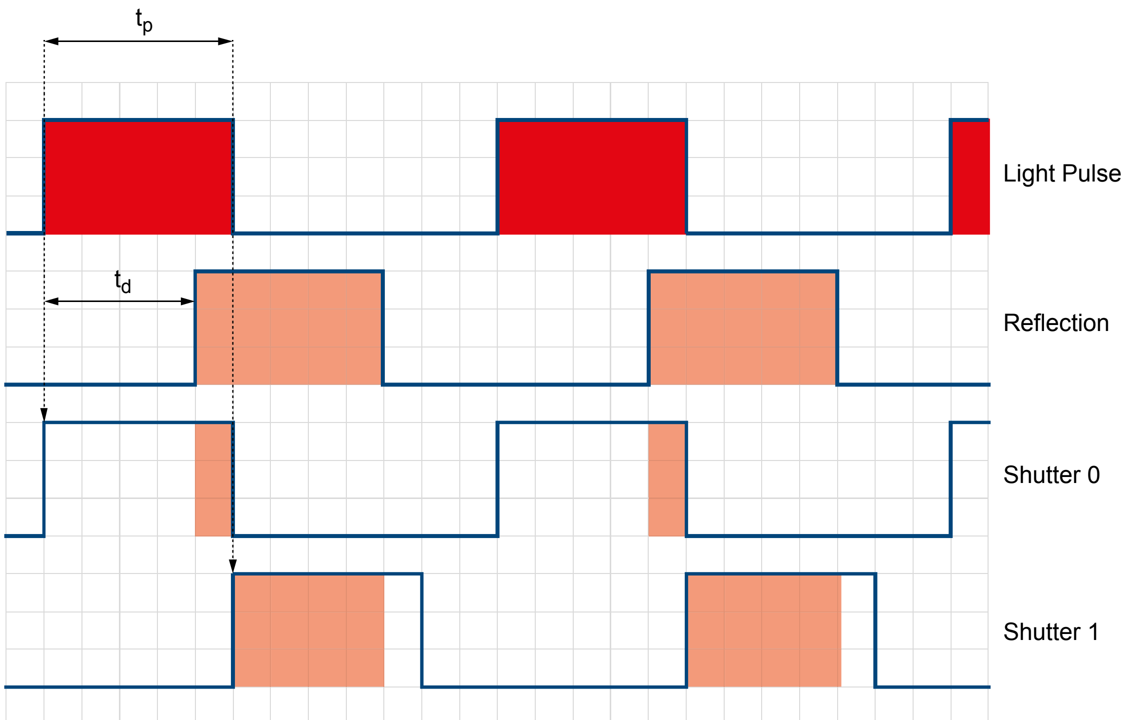


Fig. 4: Time of Flight Distance Measurement Using Pulsed Light

5.1.1 Accuracy and Repeatability

The Engineering Sample ToF cameras are calibrated for a measurement range of 0.5 to 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, the Engineering Sample ToF camera is 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:

- flat white target with over 90 % reflectivity
- in a room with zero ambient light at 22 °C
- with default settings (exposure time 15 ms)
- looking at the center of the range image
- 32 images of an area of 8 x 8 pixels are taken to account for temporal and spatial noise

The testing carried out on the Engineering Sample ToF camera has proved the accuracy to be ± 1 cm. This is illustrated in Figure 5.

The blue line in the diagram shows the measured distance compared to the actual distance (x, y axes of the diagram). The orange line represents the mean deviation for each distance measured, based on the 32 images taken per distance. The secondary y axis of the diagram (Deviation [mm]) shows that in a corridor of 0.9 to 5.5 m, the deviation typically is ± 1 cm or better. Also shown is the standard deviation (1 σ) for each measurement value.

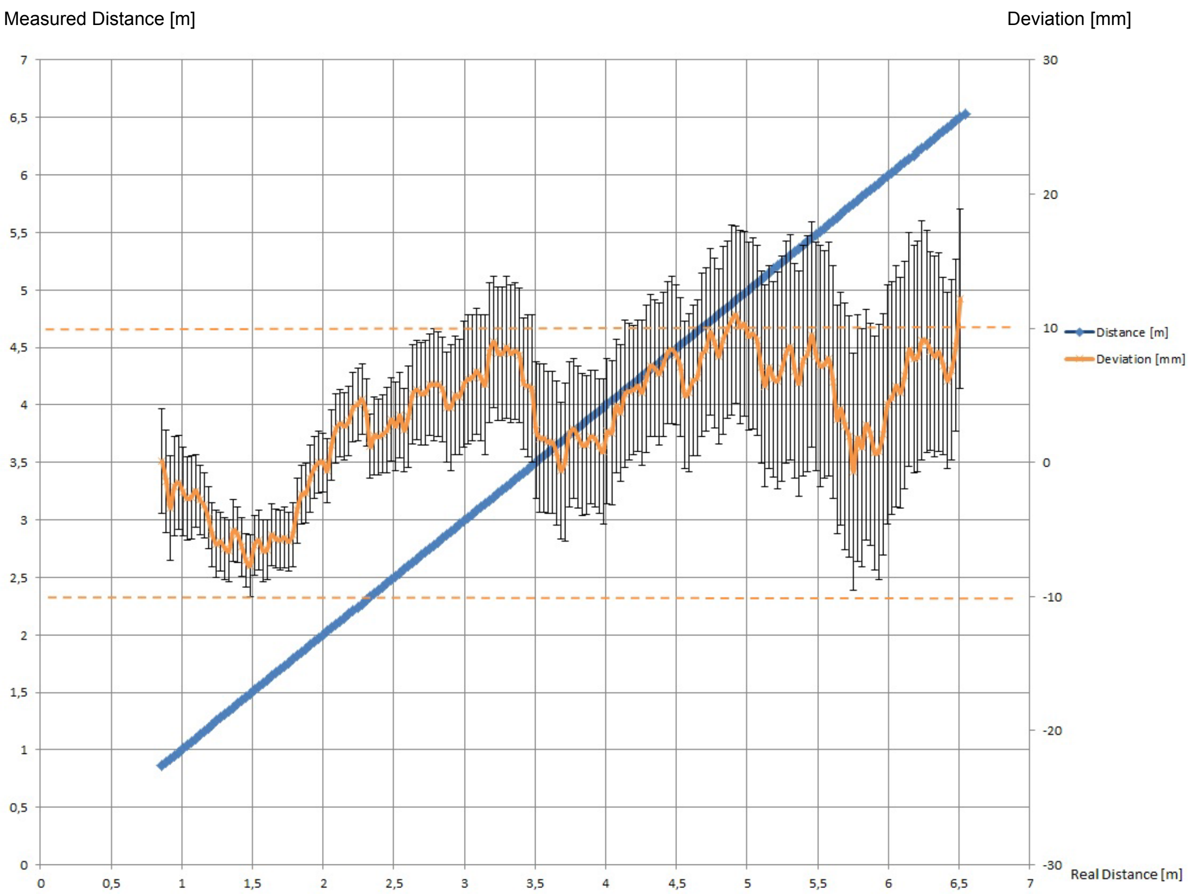


Fig. 5: Accuracy Measurement for Basler Engineering Sample ToF Camera

5.2 Influencing Factors

5.2.1 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 27.

5.2.2 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 Engineering Sample 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.

5.2.3 Temperature

To a certain degree, the electronic components used in the Engineering Sample ToF camera are susceptible to the effects of temperature.

Excessive temperatures can lead to a delayed opening of the shutter, the result of which is that the distance measured is shorter than the actual distance. For example, if the shutter is opened just 33 picoseconds later than expected, the distance measured is 1 cm too short. Exceeding the maximum temperature will also lead to increased noise in the image.

Changes in temperature, even if they are within the allowed temperature range, should also be avoided as the behavior of the camera changes in line with the changing temperature, and therefore the conditions at the start of the image capture and at the end will vary. In that case, a reliable distance measurement can't be guaranteed.

Therefore, the operating temperature range specified in Section 3.6.1 on page 10 should be observed and a stable thermal environment should be created.

For tips how to include adequate cooling measures in your camera setup, see Section 3.6.2 on page 10.

5.2.4 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.

For tips how best to plan your camera setup in order to avoid multiple reflections, see page 27.

5.2.5 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 (for example, 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 (for example, 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 5.2.4 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 and being unable to accept charges from other directions.

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

Target Object Color

Light-colored 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.

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 gain confidence in 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 Section 7.3.4 on page 35.

5.2.6 Non-Ambiguity

The non-ambiguity range of the Engineering Sample ToF camera is 0 m to 13.325 m. This means that distances of objects measured in this range reflect the object's true distance.

The problem of ambiguity arises beyond 13.325 m as the camera considers this an undefined area. The effect is that every 13.325 m a new measurement interval starts at 0 m again. This is inherent in the camera and caused by 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 14.325 m away from the camera, the distance is measured as 1 m.

Unless there are highly-reflective objects or retroreflectors in the camera's field of view, this shouldn't cause major problems, however. Most objects won't be able to reflect back sufficient light to be registered by the camera's sensor over distances beyond 13.325 m. Therefore, if you ensure that no highly-reflective objects or retroreflectors are placed within your scene, you can avoid ambiguous results.

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 7.3.1 on page 32.

6 Installation

6.1 Software Installation

To operate the Engineering Sample ToF camera, the Basler ToF Driver software package needs to be installed. For more information about this software, see page 8.

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

- pylon Viewer

  The pylon Viewer is a standalone application that lets you view and change the camera's parameter settings via a GUI-based interface.

  For more information about using the pylon Viewer, see the *Installation and Setup Guide for Cameras Used with pylon for Windows* (AW000611).
- pylon IP Configurator

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

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

  They are available under **Start** > **All Programs** > **Basler** >**ToF Driver** > **Samples**.

The software is still in the development phase. Updates are being made available at irregular intervals on the Basler website.

Should you experience problems with installing or using the software, contact Basler Support under the e-mail address support.europe@baslerweb.com.

6.1.1 Installing the Basler ToF Driver Software on Windows Operating Systems

To install the Basler ToF Driver software:

3. Close all open applications on your computer.
4. 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.

5. 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**.
6. Click **Install**.

   A message will be displayed when the installation has completed.
7. Click **Close**.

   Note that the installation program has added shortcuts for the installed features on the desktop.

6.1.2 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 Basler pylon software will not run, and vice versa.

The installation procedure described below assumes that you are going to install the pylon Camera Software Suite 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.
3. Change to the directory which contains the INSTALL file, e.g.:

   ```
   cd ~/basler-tof-driver-x.x.x-x86
   ```
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
   ```

6.2 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 4000 lx.
- Avoid mirrors or other shiny surfaces/objects in the vicinity of the camera.
- 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:

- Make sure that you have read and understood the warnings listed under "Precautions" on page 2.
- Basler pylon ToF Driver has been installed on your PC.
- 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 PC.
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 indicator 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 to 4 cm. After 20 minutes the distance measurement should be reliable.

6.3 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.

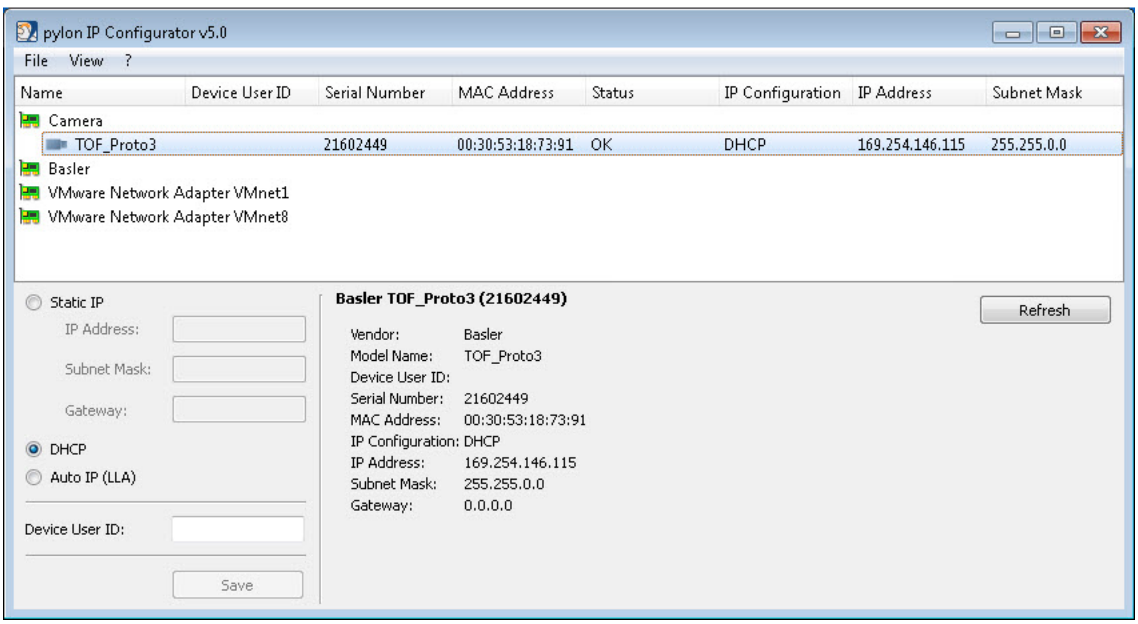
If the IP address assignment fails completely, you can manually assign an IP address using the pylon IP Configurator. The IP Configurator shows you the current IP configuration of your camera and network adapter and allows you to change it.

To open the IP Configurator:

1. **Windows:** Click **Start** > **All Programs** > **Basler** >**ToF Driver** > **pylon Viewer (ToF)** > **pylon IP Configurator (ToF)**.

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

   The camera will be displayed under the network adapter.



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

- IP Configurator online help

  The online help is available by pressing F1 in the 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

7 Camera Operation

7.1 Acquiring Images

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

To start image acquisition:

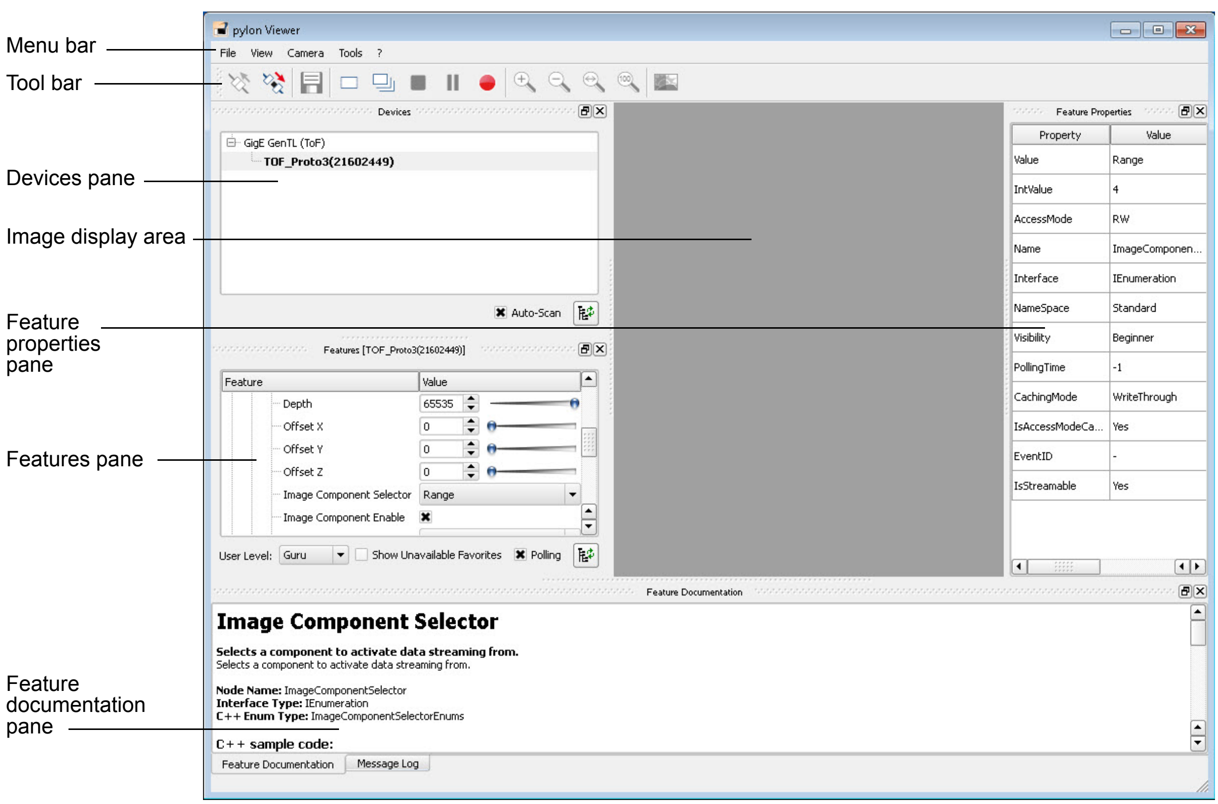
1. Connect the camera to your PC.

   See Section 6.2 on page 27 for information on how to install the camera.

   If the green LED indicator at the back of the camera lights up, the camera is ready for use.
2. Start the pylon Viewer by clicking **Start** > **All Programs** > **Basler** >**ToF Driver** > **pylon Viewer (ToF)** > **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. For more information about this, see Section 6.3 on page 28.



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.

   An image will appear in the image display area. By default, this is the Mono 16 range image.

7.2 Acquisition Control

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

- **Acquisition Frame Rate**

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

  To avoid overheating of the camera, the frame rate should not exceed 15 fps.
- **Exposure Mode**

  Currently, the only exposure mode available is the timed mode. The exposure time is set using the **Exposure Time** parameter.
- **Exposure Time**

  This parameter controls the exposure time if the **Exposure Mode** parameter is set to **Timed** 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 images taken with automatic exposure control show dark spots/areas as these may be due to oversaturation of sensor pixels. For an oversaturated sensor pixel no depth calculation is possible, which results in a black pixel in the range image.

  To avoid overheating of the camera, the exposure time should not exceed 25 ms.
- **Exposure Auto**

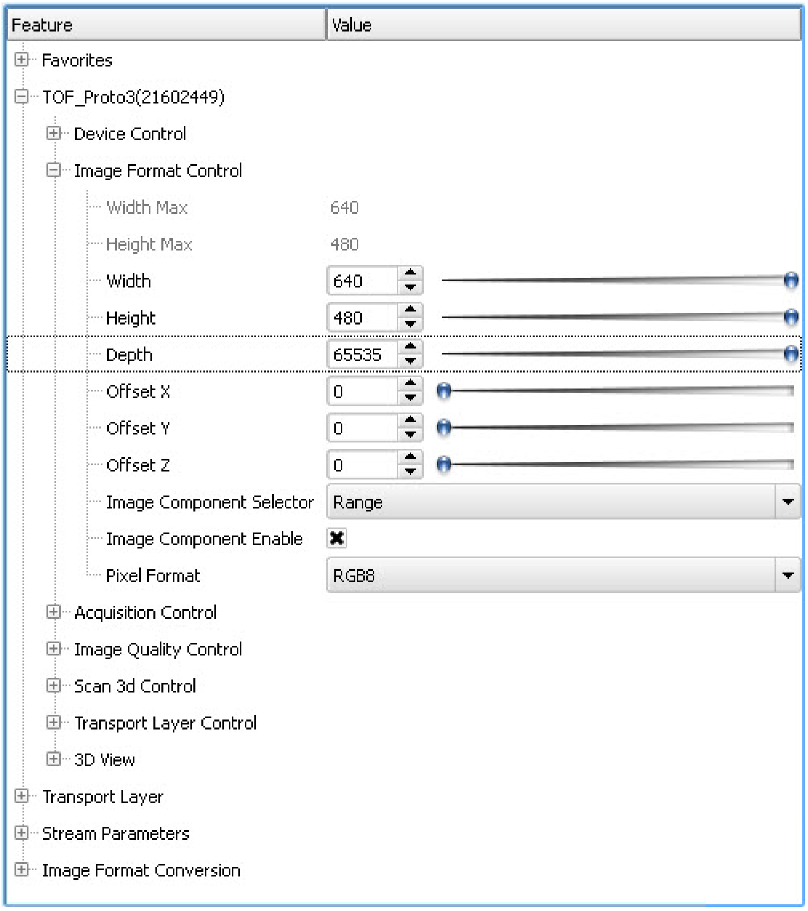
  This parameter controls whether automatic exposure control is used or not. If set to **Off**, the **Exposure Time** parameter controls the exposure duration. If set to **Continuous**, the exposure duration is constantly adapted by the camera to achieve the desired frame rate.

  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 Section 7.3.5 on page 35.

7.3 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 and choose the image components and pixel formats.



7.3.1 Setting the Region of Interest (ROI)

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

The **Depth** parameter lets you specify the actual measurement range of the camera. The available range is 0 to 65535, which corresponds to the camera's non-ambiguity range (0 m to 13.325 m).

If the desired measurement range is smaller than the maximum possible, this section can be moved within the available range using the **Offset Z** parameter. This parameter moves the ROI from the origin along the Z axis. By reducing the ROI, you basically tell the camera to ignore any data from beyond the ROI that you have defined.

i	Reducing the depth and changing the Z offset doesn't increase resolution or improve accuracy. Doing so 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 2 to 5 m from the camera, set the **Depth** parameter to 3 m and the **Offset Z** parameter to 2 m. This way, any light reflected from between 0 m to 2 m and 5 m and 13.325 m, the end of the measurement range, will be discarded. You may still get ambiguous results from the next interval (where the ROI would be between 15.325 m to 18.325 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 5.2.6 on page 24.

7.3.2 Selecting Image Components

ToF images can consist of up to three parts (components):

- Range image (default)
- Intensity image
- Confidence map

With default settings, range images in the Mono 16 pixel format are generated. To enable the other image parts, use the **Image Component Selector** and **Image Component Enable** parameters.

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

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

To view the intensity image:

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

   The image display pane now shows the intensity image.

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

7.3.3 Range Image

This is the depth image. It represents the 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.

Available Pixel Formats

- **Mono16** (default)

  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 in the image as black (near objects) or white (farther away objects).

- **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 in the image as red (near objects) or blue (farther away objects).

- **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

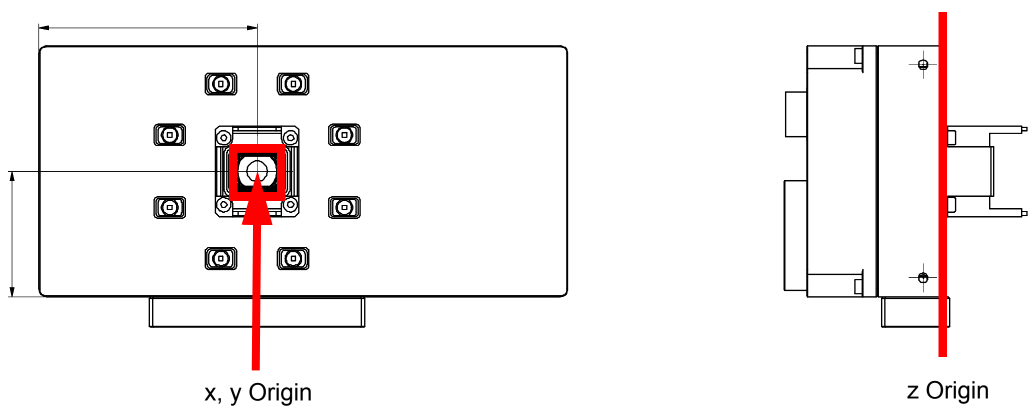


Fig. 6: Coordinate System of the Camera

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 using this pixel format, see Section 7.5 on page 37.

7.3.4 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.

Available Pixel Formats

- **Mono16** (default)
  A monochrome image using unsigned 16-bit integer values (little-endian).

7.3.5 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 darker the pixel, the more reliable the measurement. Light generated by the ToF camera itself and ambient light are considered when creating the confidence map.

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.

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 high 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.

Available Pixel Formats

- **Mono16** (default)
  A monochrome image using unsigned 16-bit integer values (little-endian).

7.4 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.

- **Spatial Filter**

  This filter uses the values of neighboring pixels to filter out spatial noise in an image. This helps to flatten bumps in planes and create smoother surfaces. Object edges are left intact.
- **Temporal Filter**

  This filter uses the values of the same pixel at different points in time to filter out temporal noise in an image. Use the Strength parameter (see below) to define how far back the memory of the temporal filter reaches.
- **Strength**

  This defines how far back the memory of the temporal filter reaches. The higher the value, the further back. Be aware that high values can cause motion artifacts, while low values reduce the efficacy of the filter.
- **Outlier Tolerance**

  This defines by how much a pixel's depth (measured in gray values of the range image) 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 image 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.

7.5 Using the Cloud Viewer

The Cloud Viewer is a tool for displaying the point cloud representation of the range image. It opens in a separate window. Each point in the cloud represents a pixel and its XYZ coordinates in a Cartesian coordinate system.

Opening the Cloud Viewer

To open the Cloud Viewer:

1. Enable the range image.
2. In the **Pixel Format** drop-down box, choose **Coord3D_ABD32f**.

   The Cloud Viewer opens.

Using the mouse, you can manipulate the point cloud in the Cloud Viewer:

- By using the mouse wheel, you can zoom in and out.
- Pressing R, resets the origin and the zoom factor.
- By pressing the +/- keys, you can increase/decrease the size of the points in the point cloud display.
- By pressing CTRL, left-clicking anywhere in the window and dragging, you can rotate the point cloud.
- By pressing SHIFT, left-clicking anywhere in the window and dragging, you can move the point cloud around.

You can change the way the coordinate system is displayed by choosing an option from the **Grid** drop-down box in the **3D View** parameter group.

Resetting the Cloud Viewer to its Original State

To reset the Cloud Viewer:

1. Click the Close button of the Cloud Viewer window.

   The window briefly closes and then re-opens in its original state.

Closing the Cloud Viewer

To close the Cloud Viewer:

1. In the **Pixel Format** drop-down box, choose a different format than Coord3D_ABC32f or disable the **Range** image component.
2. Click the Close button of the Cloud Viewer window.

   The window closes.

Saving the Point Cloud to a File

The point cloud data can be saved to a file to allow processing the data further in other software applications, e.g. CloudCompare or MeshLab.

To save the point cloud to a file:

1. In the **3D View** section of the feature tree, select the **Enable** checkbox to enable the point cloud display.
2. In the **Save Point Cloud** category, make the desired settings.
3. Next to the **Save** parameter, click **Execute**.

7.6 Calculating Distance from the Range Image

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

$$\text{dist} = g \times s$$

where:

dist = distance in mm

g = gray value of pixel in Mono 16 range image

s = 13325 mm / 65535 (scaling factor)

If you’re using the **Depth** and **Offset Z** parameters, use the following formula:

$$\text{dist} = o \times s + g \times \frac{d}{65535} \times s$$

where:

dist = distance

o = value of **Offset Z** parameter

s = 13325 mm / 65535 (scaling factor)

g = gray value of pixel in Mono 16 range image

d= value of **Depth** parameter

	Distance and Z Coordinate The distance calculated using the formulas above is the actual distance the light travels. The formulas will not give you the Z coordinate value. This is because the camera is calibrated to calculate the distance from 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. Therefore, the gray value profile produced will have a bowl-like shape.

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 *Functional Demonstrator Information* 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 3.4 on page 8, and Section 6.1.2 on page 26. 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 41.
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 14. Updated Windows and Linux installation procedures in Section 6.1 on page 25. Added Chapter 5 on page 18. 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 5.1.1 on page 19 and added Figure 5 on page 20. Deleted previous chapters 7 ("Image Acquisition") and 8 ("Camera Functionality") and moved content to new Chapter 7 on page 29. Added note in Section 7.3.1 on page 32. Added Figure 6 on page 34. Added Section 7.4 on page 36. Added information about saving point clouds to file on page 38. Added Section 7.6 on page 38.
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 5.2.6 on page 24. Section 7.3.1 on page 32. Added "Using the ROI to Reduce Ambiguous Results" on page 32. Changed the scaling factor to 13325 mm / 65535 in formulas on page 38.

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