General Description

The TOFcam-660 is a cost optimized 3D camera. It is based on the ESPROS proprietary time-of-flight technology using the epc660 TOF flagship chip. The camera controls the illumination and the imager chip to obtain distance and grayscale images. The depth images are compensated against ambient light, temperature and reflectivity of the scene. By using one of the offerd ESPROS user interfaces, 3D point clouds in a cartesian coordinate system are available. Thanks to the high performance of the imager chip with the unique ambient light suppression, the camera can be used under full sunlight condition.

This document allows a TOFcam-660 user easily to get the camera connected and started using a computer. It contains a description of all features of the device as well as all functions of GUI and ROS application. The complete description of interfaces, protocols and commands allows to connect the module to integrated systems. A software development kit (SDK) with all C++ source codes, libraries and drivers including is available by ordering the ESPROS epc660 evaluation kit.

Features

- 320 x 240 pixels QVGA resolution (76'800 pixels)
- Measurement rate up to 20 TOF measurements per second (1.5 MIO distance and amplitude values per second)
- Distance measurement and object recognition from centimeters to 100 meters
- Four different field of view and operating ranges available
- Fully calibrated and compensated
- Sun- and ambient-light tolerant up to 100 kLux
- GigE and USB interface
- Various user interfaces: GUI, ROS, Python
  - Evaluation of TOFcam-660 main features
  - Store and recall camera configuration
  - Easy collection of distance data and point clouds
  - Many explanations about “time of flight done right”

Applications

- Research in various scientific fields
- IoT applications
- Evaluation and development of an epc660 based TOF sensor
  - Automatic vehicle guidance, in-cabin monitoring
  - Object classification and safeguarding
  - Face recognition, Gesture control (man-machine-interface)

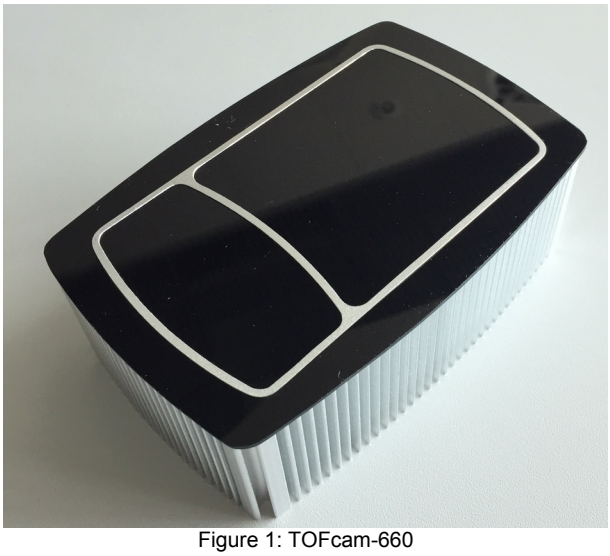


Figure 1: TOFcam-660

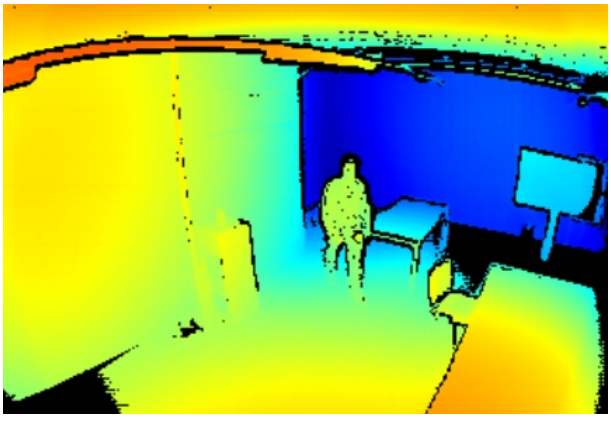


Figure 2: Color coded TOF distance

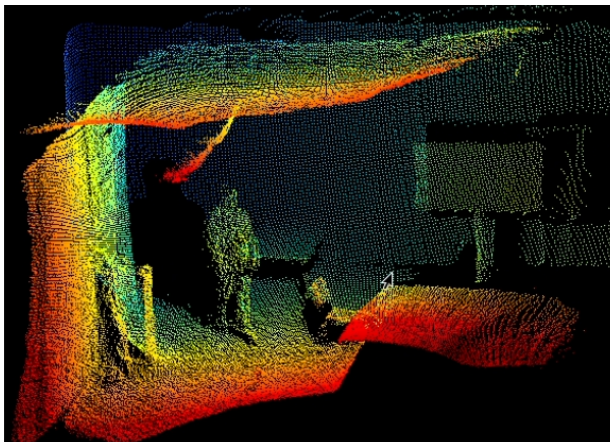


Figure 3: Point Cloud

Figure 4: Amplitude as logarithmic gray scale

Contents

1. Before you start

1.1. Precaution and Safety

	**Eye safety: Do not look directly into the camera under operation. Depending on the mode of operation, the camera device emits highly concentrated non-visible infrared light. It can be hazardous to the human eye. The use of these devices has to follow the safety precautions given in IEC 60825-1 and IEC62471.**
	The camera module is an electronic device. Handle it with the necessary ESD precaution.
	Over-voltage: Use only a power supply which correspond to the datasheet of the camera to avoid damage of the device or cause danger for humans.
	Cable-tripping: Place or mount the camera on solid ground or fix it correctly on a solid support. Place cables carefully. Falling devices can be damaged or harm persons.
	The camera comes with its own calibrated Firmware. Do not alter the Firmware without obeying the instructions herein.
	Be careful to the window surfaces of the camera. Never use any solvents, cleaners or mechanically abrasive towels or high pressure water to clean the camera.
	Operate the device in compliance with the local EMC regulations.
	This camera is not a safety device. It may not be used in safety applications, explosive atmospheres or in radioactive environment, except the user implements the required safety measures, e.g. by redundancy. However, the sole responsibility for the safety of the application is by the user.
	LIMITED WARRANTY - LOSS OF WARRANTY This camera should only be installed and used by authorized persons. All instructions in this datasheet and in the related documents shall be followed and fully complied with. In addition, the installer and user is required to comply with all local laws and regulations. The installer and user is fully responsible for the safe use and operation of the system. It is the sole responsibility of the installer and the user to ensure that this product is used according to all applicable codes and standards, in order to ensure safe operation of the whole application. Any alteration to the devices by the buyer, installer or user may result in device damage or unsafe operating conditions. ESPROS Photonics AG is not responsible for any liability or warranty claim which results from such manipulation or disregarding of given operating instructions.
epc espros photonics corporation	ESPROS Photonics AG is an ISO 9001: 2015 certified company.
CE RoHS	This product is according to European Union standards and free of hazardous substances.

1.2. Updates

ESPROS Photonics is constantly striving to provide comprehensive and correct product information. Therefore, please check ESPROS' website regularly for updated versions of datasheets and documentations: www.espros.com

	Download the latest Flyer of TOFcam-660.
	Download the latest Installation and Operation Manual of the TOFcam-660.
	Download and use the latest software package “TOFCAM660_FPGA_SW_Package” containing a graphical user interface (GUI) for Windows or, Mac computers and a robot operating system (ROS) application If there are any questions, please contact your ESPROS sales office or send an email to sales@espros.com.
	Download and use the latest software development kit (SDK) “SDK_TOFCAM660_FPGA” containing all source codes of the firmware, GUI and ROS. Unpacking the SDK is password protected. Get back to ESPROS to check whether you fullfill the requirements to get the password.

1.3. Important Notes

Notes on PRELIMINARY versions:

THIS MANUAL IS UNDER CONSTRUCTION. IMPORTANT PARTS MAY BE MISSING

Colored marking in text means “under consideration” and refers to not yet applicable or verified information.

Values and/or information are either estimates or show the applicable principle only.

2. Abbreviations

Designator	Description
3D	Three dimensional
ACK	Acknowledged
ADC	Analog-to-digital converter
API	Application Program Interface
Binning	Summation of a defined number of pixels. Binning can be done in the charge (analog) or in the digital domain
CMD	Command
CPU	Central Processing Unit
CRC	Cyclic redundancy check (checksum)
cwTOF	Continuous wafe modulated time of flight
DCS	Differential correlation sample
DLL	Delay locked loop, controllable delay line
DRNU	Distance response non-uniformity: Distance error from pixel to pixel with a target at the same distance
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
ESD	Electrostatic discharge
FoV	Field of view
fps	Frame rate, number of images per second
Frame	One image
GigE	Gigabit Ethernet
GND	Ground terminal, negative supply voltage
GPIO	General Purpose Input / Output
GS	Grayscale
GUI	Graphical User Interface
HDR	High dynamic range
ID	Identifier
IN	Input terminal which is used to sense a high or low voltage
IP	Internet Protocol address
ISO	International organization for standardization
JEDEC	Joint electron device engineering council
LAN	Local Area Network
LED	Light emitting diode used to illuminate the scenery or as indicator
LSB	Least significant bit
LVTTL	Low voltage transistor transistor logic
MSB	Most significant bit / byte
NACK	Not acknowledged
NF	Narrow field of view
OUT	Output terminal which is can be set to high or low voltage
QVGA	Quarter Video Graphics Array
RMS	Root mean square
RoHS	Restriction of hazardous substances
ROI	Region of interest in the pixel-field
ROS	Robot Operating System
RX	Receive terminal, data in
SDK	Software Development Kit

Designator	Description
SF	Standard field of view
SW	Software
TBD / tbd	To be defined, information not yet available or not valid
TOF	Time of Flight
TTL	Transistor transistor logic
TX	Transmit terminal, data out
UART	Universal asynchronous receiver transmitter
USB	Universal Serial Bus
UWF	Ultra wide field of view
VDD	Positive supply voltage
WF	Wide field of view

Table 1: List of abbreviations used in this document

3. Quick guide

3.1. Connecting the camera module

First of all you need to prepare a power supply for the camera. Therefore use the 6 pin connector which is included in the scope of delivery. If you ordered the power supply and power adapter cable as accessory according to chapter 4.3 then you don't need to provide a separate power supply connected to this 6 pin connector.

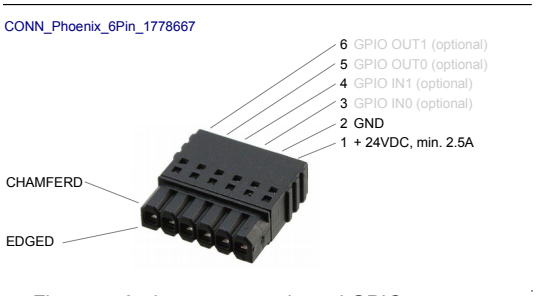


Figure 5: 6-pin power-supply and GPIO connector

You need to install the Graphical User Interface onto your computer. This is available with the software package "TOFCAM660_SW_Package" from our download page.
You need to consider the IP address of the camera which is 10.10.31.180 with sub-net mask 255.255.255.0. So you need to operate the camera within the same network range. If your computer has a RJ45 LAN connector you can connect the camera directly with corresponding network settings of the LAN-adapter in your computer. You can choose a manual IP 10.10.31.190 for your computer e.g. If you use a RJ45 to USB adapter you need to configure the settings of your USB adapter accordingly. You can choose a manual IP address 10.10.31.190 for your USB adapter e.g. Disable the firewall on your computer or add an exception for the camera application. The firewall might block the visual-ization of data in the image window.

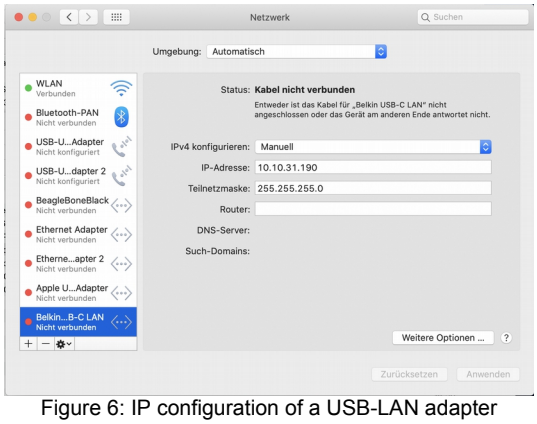


Figure 6: IP configuration of a USB-LAN adapter

- Connect your camera with your computer using a RJ45 patch-cable.
- Connect your camera to the proper voltage using the prepared power supply.
- Start the GUI on your Computer. The connection to the camera will be indicated in the corner bottom left of the main window of the GUI (Connected to 10.10.31.180 - in green letters). This can take around 60 seconds. If there is no connection for several minutes then please disconnect and re-connect the power supply. If this don't help you need to check the network settings of your network adapter as described previously.

3.2. Camera settings

- Disable all Filter functions. Set the "Integration Time 3D high" to zero. Choose Image Type "Distance".
- Depending on the maximum distance in your field of view you should choose a suitable "Modulation frequency" (unambiguity).
- If you choose a modulation frequency which is not 24MHz or 12MHz (6MHz e.g.) the camera is not calibrated. In this case it might be required to set a corresponding offset.
- Set the "Distance Range max." value to the effective maximum distance in your scenery.
- For object detection set the "Minimum Amplitude" to 50 LSB, for accurate measuring to 200 LSB (this are good starting points, fine-tuning possible). Start streaming with the “Start” button.
- Increase / decrease the "Integration time 3D low/single" to a value where you get a distance picture of the most far objects you would like to see.
- Increase the "Integration time 3D high" to a value where saturation (purple), ADC overflow (pink) and invalid (black) pixels are removed or reduced to a minimum (normally this value is about 10 ... 20% of the "Integration time 3D low/single" value).
- Play with filtering: enable "Temporal Filter" e.g.
- Optimize the color scale (visual graduation) of the relevant objects in your scenery by changing the "Distance Range min." value.
- Change the image type to the illustration of the scenery you like to see.

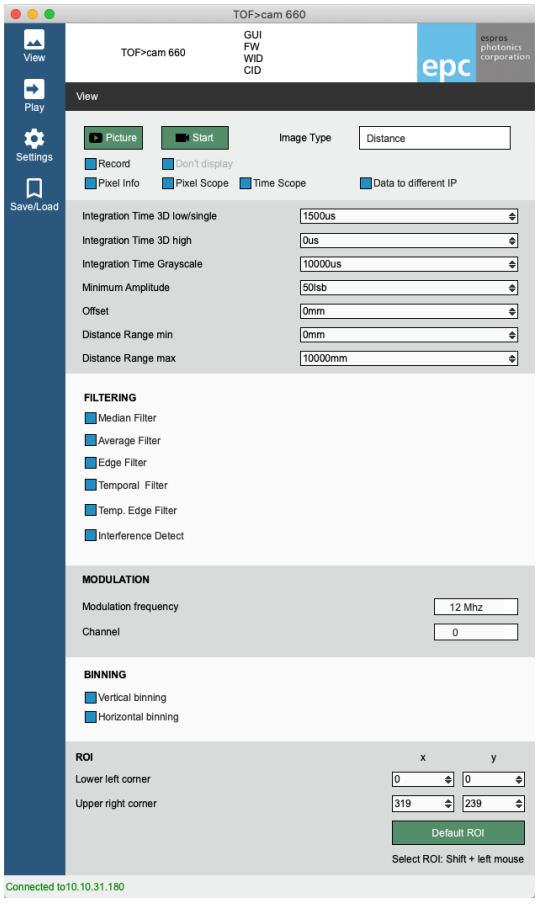


Figure 7: GUI window for camera settings

4. TOFcam-660 time of flight camera

4.1. System overview

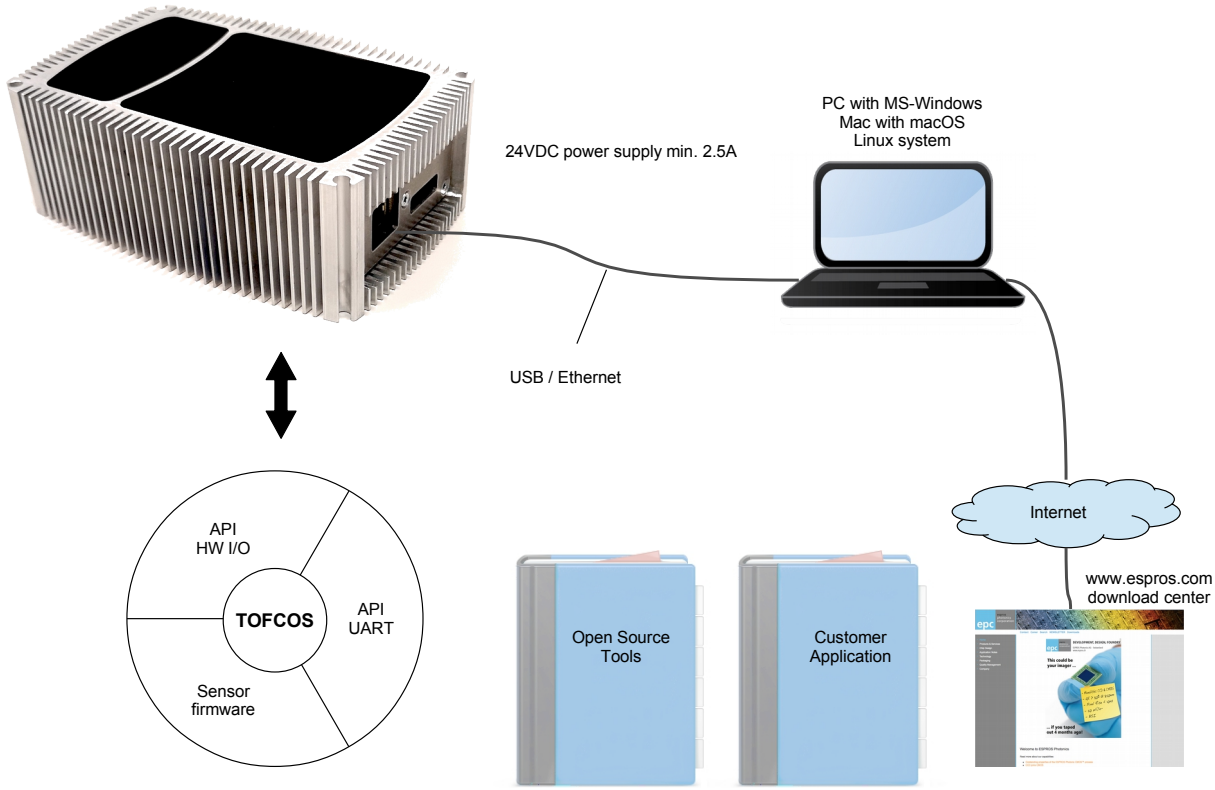


Figure 8: TOFcam-660 system setup

The TOFcam-660 is a general purpose camera based on the ESPROS epc660 cwTOF imager chip:

- 24VDC power supply input
- RJ45 LAN connector
- General purpose I/O connector
- FPGA/SoC Module Mars ZX2 Xylinx Zynq 7010
- The FPGA board communicates with the epc660 chip carrier board through an ultrafast TCMI seraial interface.
- One out of thee differrent lenses depending on the camera model focus the reflected light from the scenery onto the pixel field of the imager chip.
- NIR band pass filter, AR coatings and straylight suppression for optimal optical performance
- LED illumination adopted to the sepcific field of view
- Firmware for camera control, distance calculation and filtering
- Communication by Ethernet
- ROS device drivers for Linux available
- Windows and Mac GUI available

4.2. Scope of delivery

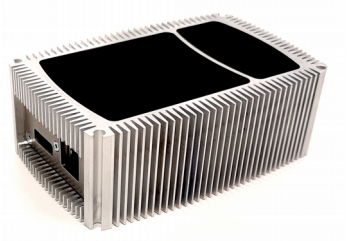
Pieces	Part Name	Picture
1	Time of Flight Camera TOFcam-660-FPGA consisting of: – Aluminum housing – Receiver optic – Illumination cpl. – CPU electronics – interfaces	
1	6 pin connector plug for 24V power supply and GPIO – Plug with snap-fit clamps – Connecting instructions – Pin assignment	
4	Self tapping screws for camera mount	
1	Software package containing GUI, ROS and current Firmware. Available on the ESPROS download page.	
1	Documentation (useful additional information available on the Espros download page)	

Table 2: Scope of delivery

4.3. Ordering information

Picture	Part No.	Name	Description
	P100 592 P100 593 P100 594	TOFcam-660-NF-940-FPGA TOFcam-660-SF-940-FPGA TOFcam-660-WF-940-FPGA	FoV 31 x 24°, 60m operating range FoV 70 x 51°, 15m operating range FoV 108 x 77°, 9m operating range
	P100 638	Connector plug	6 pin connector plug for power supply and GPIO
	P100 609	Power adapter cable	Cable to connect a TOFcam-660-FPGA directly with the power supply P100 282
	P100 282	Power Supply 24VDC with DC cable L = 1.2m	Input 100 … 240V DC output: 24V, 2.5A
	P100 284	Power cord 2 pole L = 1.8m	CH/EU plug

	P300 189	Power cord adapter CH/EU - US	
	P300 780	Batch cable RJ45 L = 2.0m	
	P300 781	Adapter RJ45 to USB	GigE

Table 3: Order information for cameras and accessories

4.4. Technical data

All characteristics are at typical operational temperature T_A = +25ºC

Parameter	Description	Conditions	Min.	Typ	Max.	Units	Comments
V_{DD}	Main supply voltage	Ripple [1] < 50 mV_{pp}	_	24	_	VDC	
I_{DD}	Supply current		_	_	_	A	
λ	Operating wavelength			940		nm	
RES_{IMAGE}	Image resolution			320 x 240		Pixel	QVGA
FoV	Field of view	Version NF		31 x 24		°	Refer to Chapter 4.3
		Version SF		70 x 51		°	
		Version WF		108 x 77		°	
D_R	Operating range	Version NF	0.5		60	m	Object recognition, 50 LSB on 90% reflective target
		Version SF	0.2		15	m	
		Version WF	0.2		9	m	
D_M	Measuring range	Version NF	1		30	m	Accurate distance measuring, 200 LSB on 90% reflective target
		Version SF	0.5		8	m	
		Version WF	0.5		5	m	
Acc	Accuracy, measuring range min. … 2m			± 4		cm	Mean of 100 samples
	Accuracy, 2m … measuring range max.			± 2		%	
D_{NOISE}	Distance noise (1σ value)			0.1		mm	
f_{MOD}	Modulation frequency selecteable		0.75		24	MHz	Refer to unambiguity range
$D_{Unabiguity}$	Unambiguity range [2]	@ f_{MOD} = 24MHz		6.25		m	
		@ f_{MOD} = 12MHz		12.5		m	
		@ f_{MOD} = 6MHz		25		m	
		@ f_{MOD} = 3MHz		50		m	
		@ f_{MOD} = 1.5MHz		100		m	
		@ f_{MOD} = 0.75MHz		200		m	
f_{SHIFT}		Channel 0		0			To avoid interference in multi camera operation environment
		Channel 1		- f_{MOD} / 30		MHz	
		Channel 2		- f_{MOD} / Ґ 34		MHz	
		Channel 3		- f_{MOD} / 40		MHz	
		Channel 4		- f_{MOD} / 48		MHz	
		Channel 5		- f_{MOD} / 60		MHz	
		Channel 6		- f_{MOD} / 80		MHz	
		Channel 7		- f_{MOD} / 120		MHz	
		Channel 8		- f_{MOD} / 240		MHz	
		Channel 9		+ f_{MOD} / 240		MHz	
		Channel 10		+ f_{MOD} / 120		MHz	
		Channel 11		+ f_{MOD} / 80		MHz	
		Channel 12		+ f_{MOD} / 60		MHz	
		Channel 13		+ f_{MOD} / 48		MHz	
		Channel 14		+ f_{MOD} / 40		MHz	
		Channel 15		+ f_{MOD} / Ґ 34		MHz	
		Channel 16		+ f_{MOD} / 30		MHz	
t_{INT}	Integration time selectable for distance		1		4'000	µs	
	Integration time selectable for gray scale		1		100'000	µs	

Parameter	Description	Conditions	Min.	Typ	Max.	Units	Comments
t_{CYCLE}	Measurement cycle time for full TOF image			_		s	@ t_{INT} = 1'000µs
t_{PWR_UP}	Power up time until acceptance of commands				1.5	s	
t_{WARM_UP}	Warm-up time until output data is in tolerance			_		s	Refer to Chapter Fehler: Referenz nicht gefunden
Φ_{AL}	Ambient-light suppression			100		kLux	Indirect, on target
T_A	Ambient temperature range		-20		60	°C	Operation and storage
RH	Relative humidity		15		90	%	Non-condensing
W	Weight			_		g	Without cable
ESD	Electrostatic discharge rating		JEDEC HBM class 1C (1kV to < 2kV)				Human body model
EMC / EMI	EMC emission		EN 61000-6-3:2011, EN 61000-6-2:2005				
	Eye safety		IEC62471:2013				Refer to Chapter 1.1.

Table 4: Technical data

Notes:

1 Min. and Max. voltage values include noise and ripple voltage

2 The camera uses the continuous-wave TOF phase-shift measurement technique. Highly reflective objects outside of the unambiguity distance will appear closer due to the wrap-around of the modulation period.

4.5. Mechanical data

4.5.1. Mechanical features

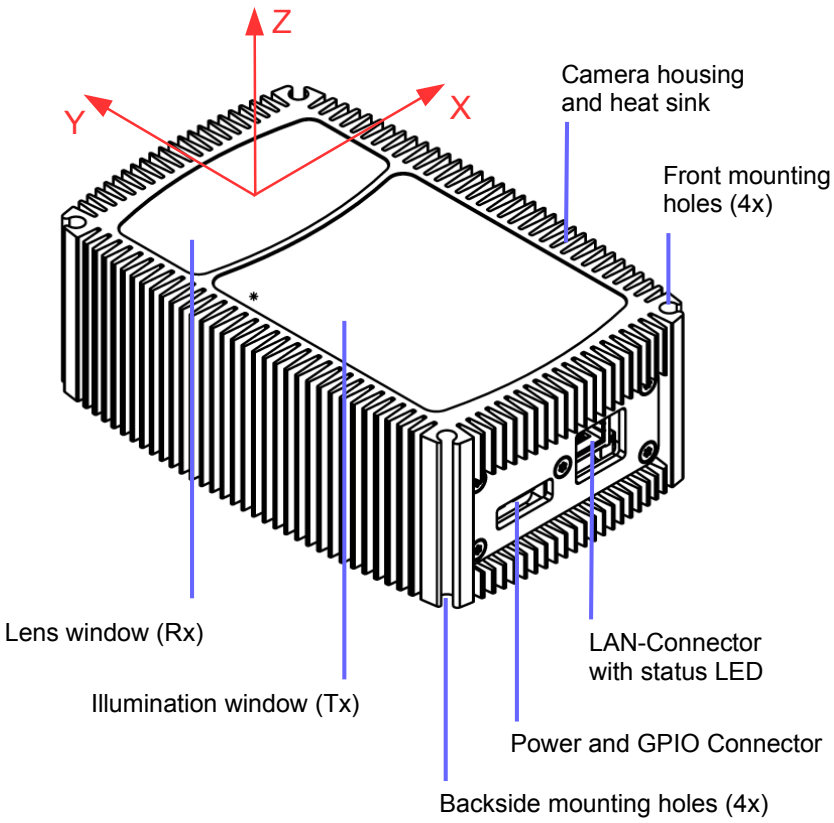


Figure 9: Mechanical features

4.5.2. Mechanical dimensions

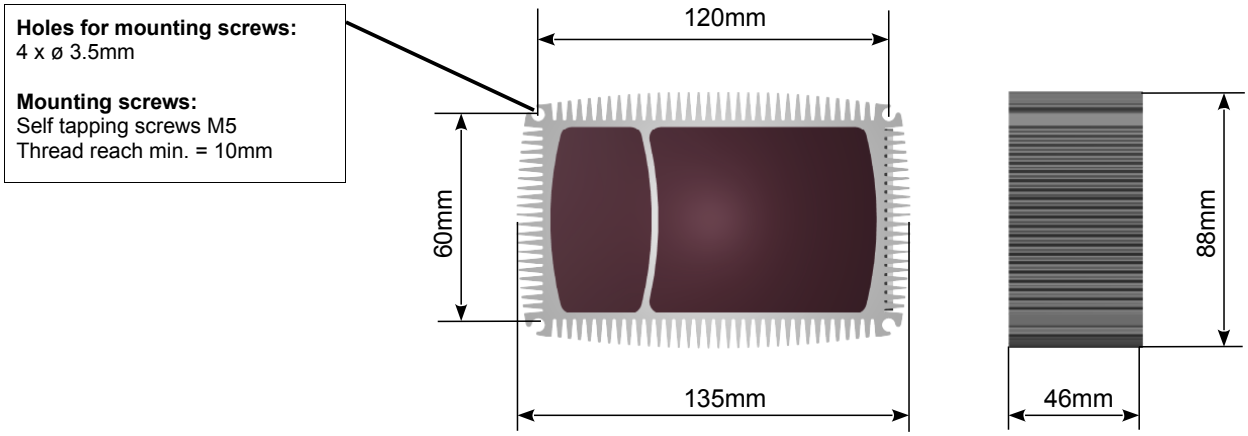


Figure 10: Mechanical dimensions

4.6. Camera connectors

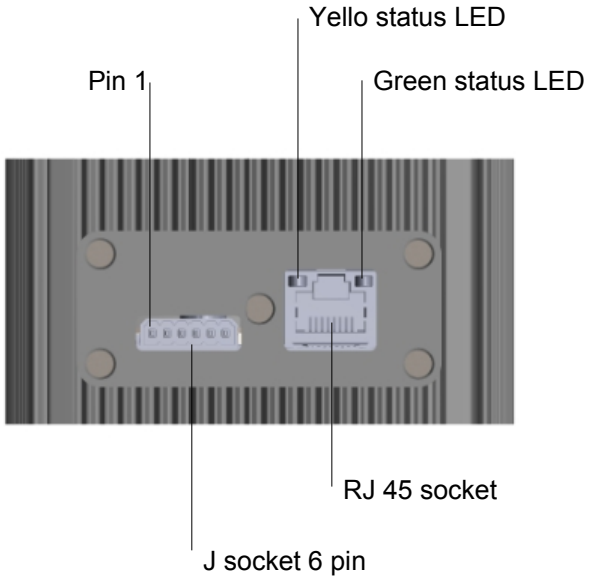


Figure 11: Camera connectors

4.6.1. LAN connector

Connector type:	THD Connector RJ45, 8P8C 1000BASE-T
Matching plug:	any RJ45 8P8C plugs
Accessory:	LAN cables and GigE to USB adapter avaiable as accessories. Refer to Chapter 4.3.

4.6.2. Power and GPIO connector

Connector type: Term Block, R/A, 6 Pos STR 2.5mm
Matching plug: Term Block Plug, 6 Pos STR 2.5mm
Accessory: For matching connector plug refer to Chapter 4.3.

No.	Name	Function	Comments
1	VDD	VDD: +24V	Stable and free of noise power supply for the imager section.
2	GND	Negative supply terminal	
3	PIN3	IN 0	Open-drain output, refer to Chapter Fehler: Referenz nicht gefunden
4	PIN4	IN 1	
5	PIN5	OUT 0	Digital input, refer to Chapter Fehler: Referenz nicht gefunden
6	UART_TX	OUT 1	

Table 5: Pin table

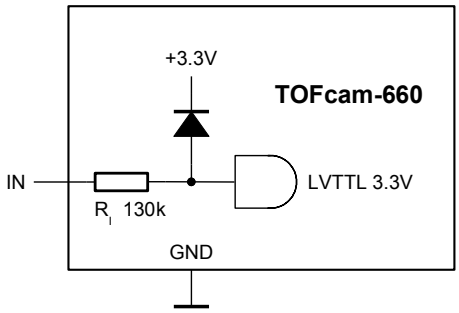


Figure 12: Input pins IN 0 and IN 1

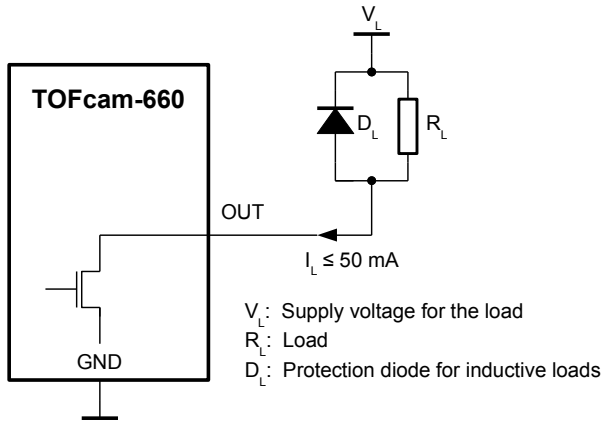


Figure 13: Output pins OUT 0 and OUT 1

⚠	Make sure to use the right plug and insert it properly to avoid damage of the device connector!

4.7. Start up

The camera has a factory set IP address which is 10.10.31.180 with a sub-net mask 255.255.255.0. You need to adjust the network settings of the host computer according to this address. The LAN needs a 1000MB/s capability. Ensure that your firewall do not block the data vizualization in the image window. In most cases you need to disable the firewall or to set an exception for the camera application.

❗	Get back to your IT department in case of network communication problems.
⚠	To change the IP address of the camera it is required to disassemble the camera to get access to the program memory. Please contact your ESPROS sales office or send an email to sales@espros.com to get instructions how to do that.

- Connect your camera directly with your computer using a RJ45 patch-cable or additionally using a Gig-E capable RJ45 to USB adapter.
- Connect your camera to the proper voltage using the prepared power supply.
- Start the GUI on your Computer.

The device notifies the power-up with a constantly lighting green LED. During network communication start-up the yellow status LED is flashing. This can take up to 60 seconds. In the corner bottom left the GUI shows the network connection status.. If there is no connection for several minutes then please disconnect and re-connect the power supply. If this don't help you need to check the network settings of your network adapter as described previously.

Error cases:

- If the green status LED do not ligth then the camera is not connected to a suitable power supply or not connected to a network adapter.
- If the GUI indicates the camera as “Disconnected from 10.10.31.180” then the network settings are incorrect.
- If the GUI indicates the camera as “Connected to 10.10.31.180” but “Star”t a data stream do not open an image window then the firewall blocks the application or the LAN has no Gig-E capability.

5. GUI

First, before installation of a new software release, read the README and CHANGELOG files of the download package to get latest product information.

5.1. GUI main window

After starting the “ESPROS_TOFCAM660_GUI” application, the control window of the GUI appears. The software connects automatically to the device if a camera is physically connected to the computer. The connection is indicated in the status indicator line in the footer of the control window, the header shows the GUI version in use, the current firmware installed on the camera as well as the wafer and chip ID of the epc660 imager. The menu selection on the left side bar allows a user to step into the GUI control options.

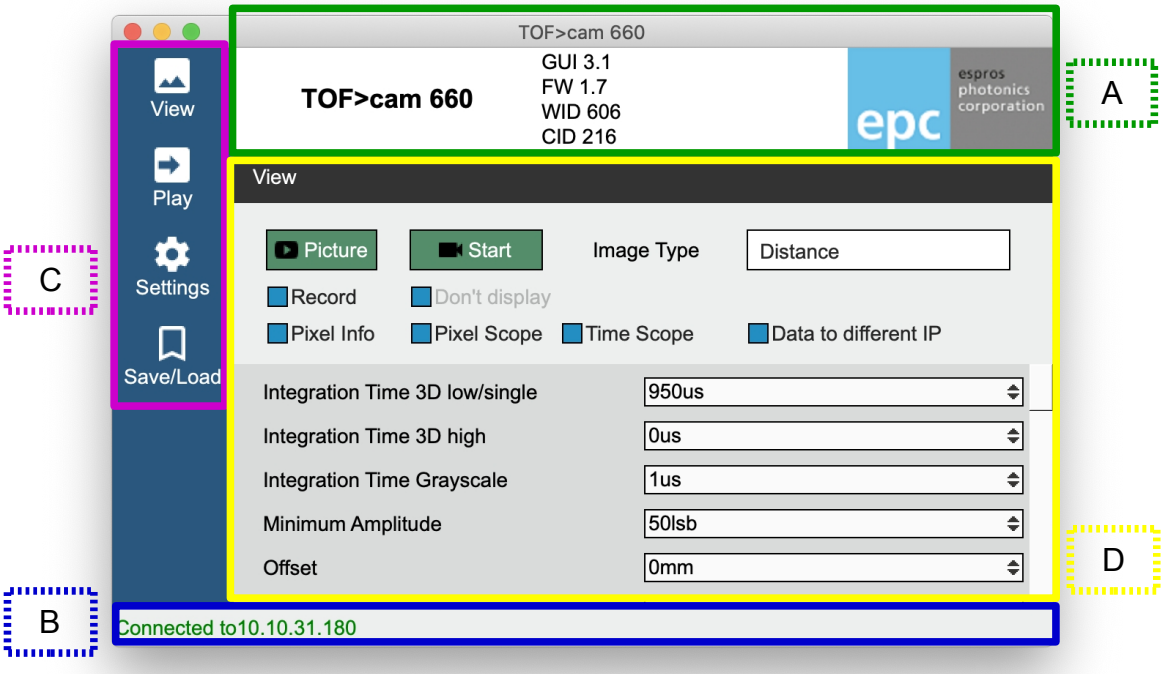


Figure 14: Sections of the GUI main screen

A) Icamera type, GUI version, Firmware version, Chip-/Wafer-ID of the epc660 in the camera

B) Connection status:

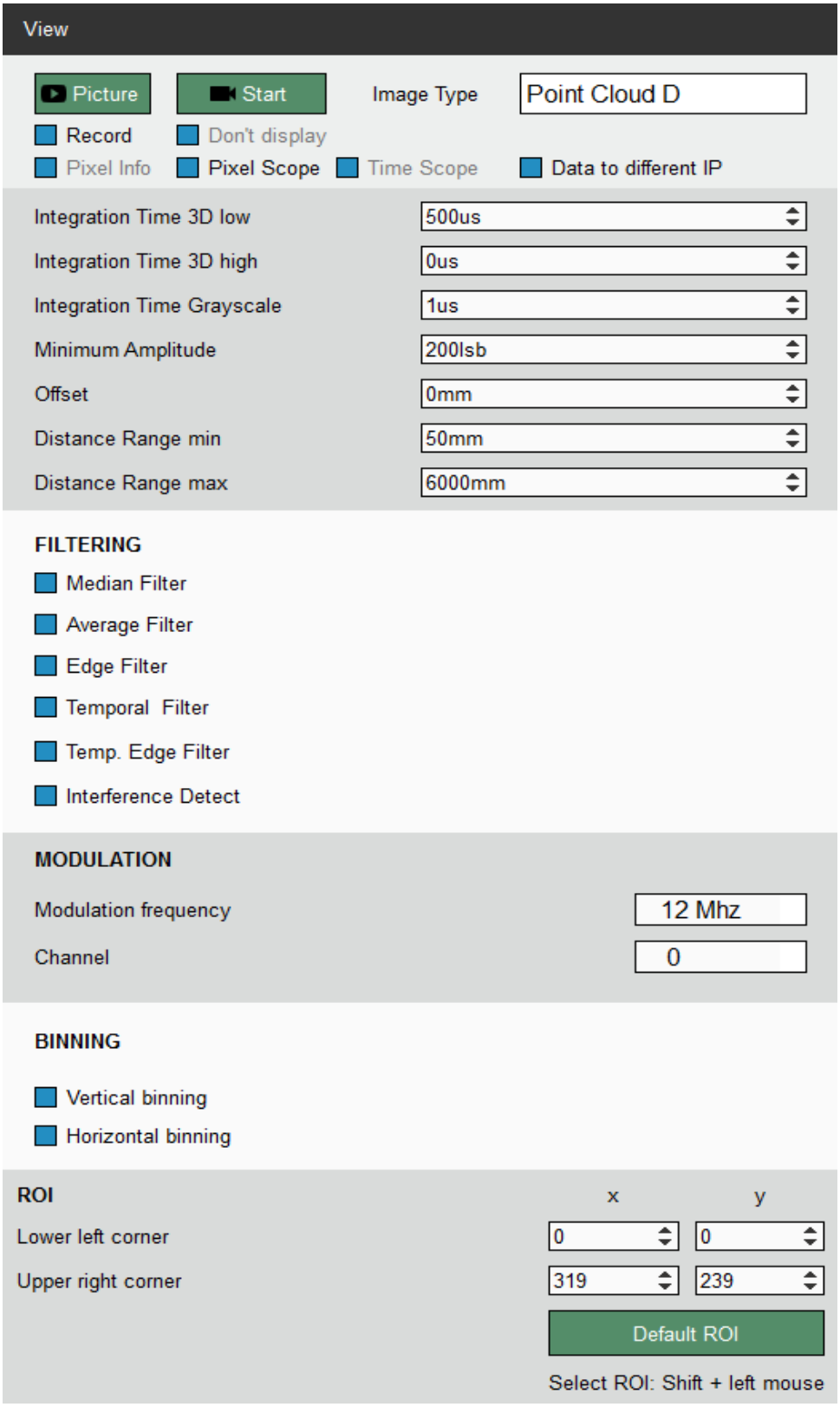
C) Menu tab

View	Chapter 5.1.1
Play	Chapter Fehler: Referenz nicht gefunden
Settings	Chapter 5.1.6
Save/Load	Chapter 5.1.7

D) Controls for the selected menu tab

5.1.1. View menu

The View menu allows to control the camera and the camera output. Distance, amplitude and gray-scale images can be captured, streamed or recorded. Detailed information about pixel groups or one single pixel can be illustrated.



- "Picture" and "Start" open the "Image" window according to the selection in the "Image Type" drop-down menu. Please see Chapter Fehler: Referenz nicht gefunden to read the details about the live image window. The "Picture" button acquires one single frame while the "Start" button starts a live stream. It changes its look to "Stop" which allows terminating the streaming.
- "Record" function allows to save picture data (one picture per push on the "Image" button) or as live stream (from "Start" to "Stop" command each). On computers with low performance it might be helpful to enable the "Don't display" function to use all resources for recording the live stream. The recorded data contains all values according to the selected "Image Type".
- Data to different IP" allows to stream the data record to another device than the GUI controls the camera. Refer to Chapter 5.1.6 how to select the IP of the receiver.

- The “Info” and “Scope” check boxes open additional windows with dedicated information. You will find additional description about these functions in Chapter 5.1.5.
- “HDR off“ let's the camera operate with one integration time only.
- “HDR spatial“ operates all odd rows of the imager with the “Integration Time 3D 0“ value and all even rows with the “Integration Time 3D 1“ value.
- “HDR temporal“ allows using up to 4 different integration time values (integration time values with zero values are ignored). In this mode one complete image is acquired with each set integration time 3D 0 … 3. After the acquisition of all frames, a new image is generated from the different frames by using the most confident value (pixel by pixel)l. Due to multiple image acquisi - tions, this mode reduces the frame rate.
- Integration time setting allows to define the exposure time to acquire one Differential correlation sample (DCS). Four DCS' are required for distance acquisition.
- For each integration time, a minimal amplitude can be set. This is the minimum received signal to provide distance. One should use low limits for object recognition but high limits for accurate distance measurements. Please investigate the TOF theory to become familiar with the physical context. A very helpful lecture might be the book “3D-TOF, A guideline to 3D-TOF sensors that work” by ESPROS Photonics Corp. (author Beat Dede Coi et. al.).
- “Offset“ shifts the zero distance from its original z-axis zero point (refer to Figure 7).
- “Minimum distance“ cuts off all pixels reporting a value closer than this setting. In addition, the color distance scale is adjusted this setting.
- “Maximum distance“ cuts off all pixels reporting a value beyond this setting. In addition, the color distance scale is adjusted this setting.
- The color scale visualizes distance of every pixel in the viewer.
- Various powerful filter functions are available.
- To avoid interference issues due to unknown systems disturbing the sensor a “Interference detection“ can be enabled. Interfered pixels will be detected automatically and indicated as “invalid data”. By selecting the “use last value“ function the last valid value is sent for the affected pixel instead of marking it as invalid. This function is also be used to suppress motion blur.
- The modulation frequency defines the unambiguity range. Refer to Chapter 4.4
- “Modulation channel” allows a shift of the modulation frequency to the main (default) modulation frequency. Multiple cameras operating in the same scenery (full or partially) with the same modulation frequency will interfere each other which leads to sporadically wrong distance information. This can be eliminated if the cameras do not use the same modulation frequency.
- Binning horizontal and vertical
- The ROI (region of interest) allows to reduce the active pixel field. Only pixels within the selected ROI will be acquired. The “Default ROI” button resets the ROI to full imager size of 160 x 60 pixels.
- Tooltips are available by moving the cursor either to the corresponding text (refer toFigure 12).

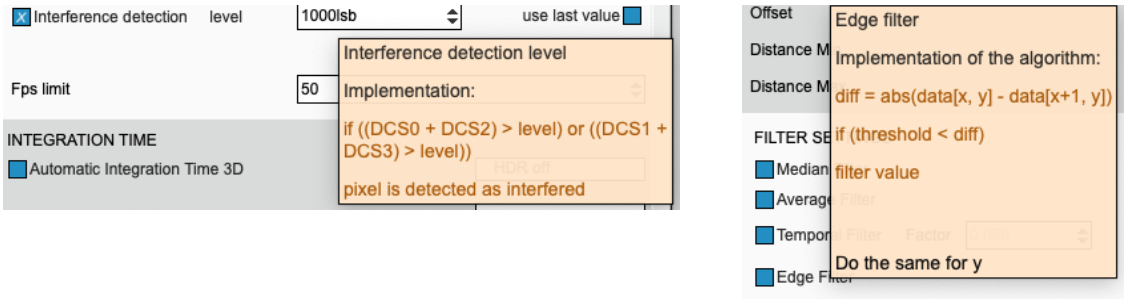


Figure 15: Tooltip examples

5.1.2. Play menu

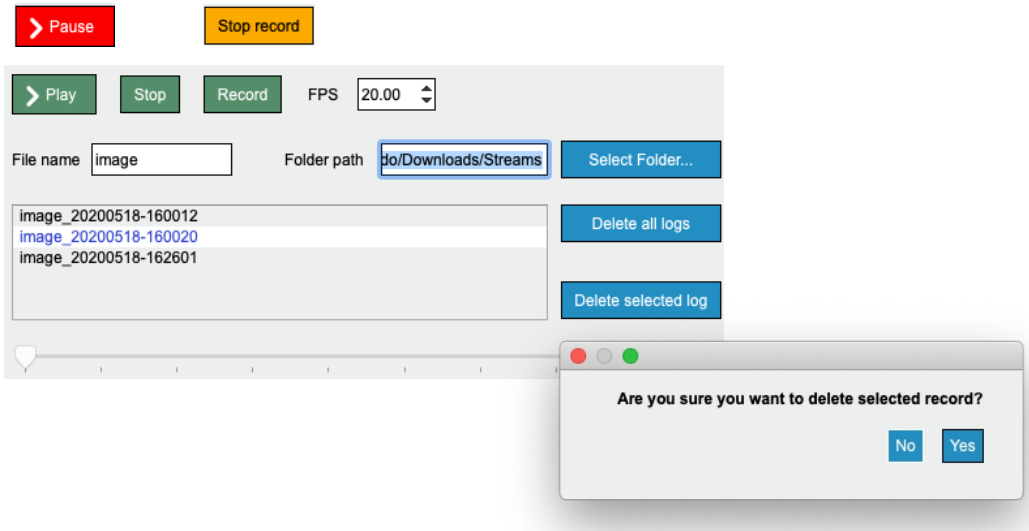


Figure 16: Player controls

- "Play" replays the selected stream with the set frame rate. After changing the selection or pushing the "Stop" button the original frame rate of the recording is used. The "Start" button changes its look to "Pause" after been pushed. Selecting the "Pause" button interrupts the playback and allows to continue from the same point.

  The player can replay the recorded data only with the parameters which has been set during the recording process. This includes also the "Image Type" according to the "View" menu.
- "Stop" aborts the replay, resets the timer to zero and the frame rate to the recording frame rate.
- "Record" streams images according to the parameters set in the "View" menu, refer to Chapter Fehler: Referenz nicht gefunden.
- "FPS" sets the acquisition frame rate (or the replay speed respectively). This value is reset by pressing the "Stop" button or by changing the selected log in the list.
- "File name" defines the file name of the log file. An "underline" character separates this name from the current calendar day followed by a "minus" separated time stamp.
- "Folder path" defines the log file location. It path can be changed either directly in the input field or with the "Select Folder" function.
- "Delete all logs" will delete all logs in the selected folder. "Delete selected log" deletes the selected log only. All deletions needs to be confirmed by the user.
- "Convert to PCD" will convert the selected log from binary files to PCD point cloud files using same file name and file path. The point cloud contains x, y and z coordinates per pixel and the values for measured distance.
- "Convert to PCDA" is only enabled for binary files recorded as distance and amplitude files. This command converts binary files to PCD files containing x, y, z and intensity values.

5.1.3. Live image window

The "Image" window pops-up after a streaming, a replay or a recording has been started from the "View" or the "Play" menu. The window contains the images according to the selected "Image Type". A recorded streaming contains only the data which has been selected during the recording process.

Live image window showing all different image types.

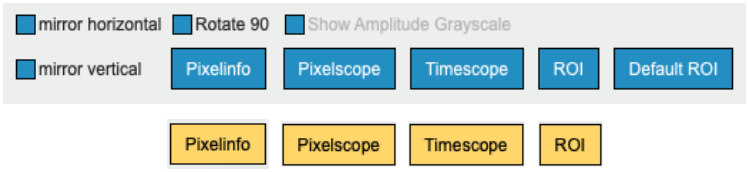
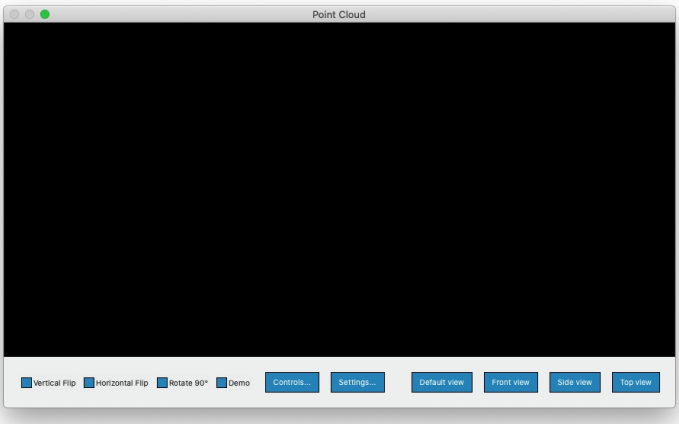


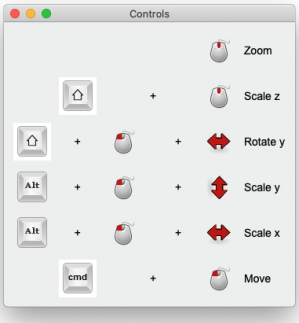
Figure 17: Live view controls

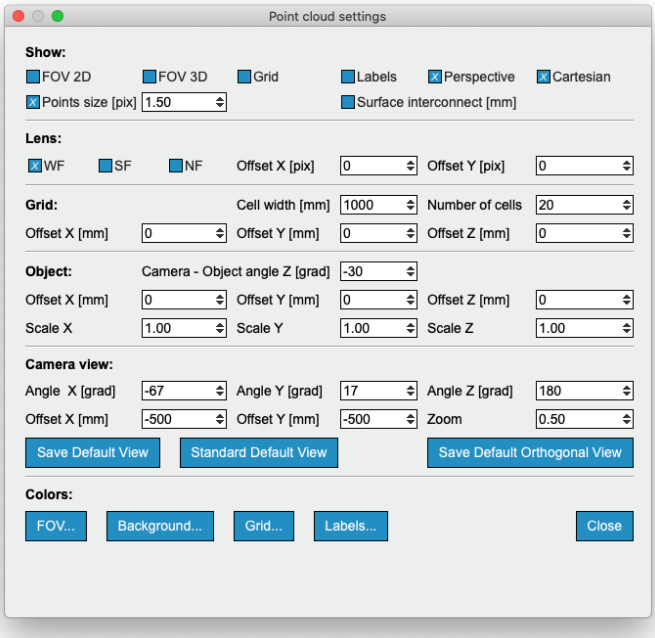
- “Mirror horizontal“ flips the image horizontally.
- “Mirror vertical“ flips the image vertically.
- “Rotate 90°” rotates the image.
- The amplitude can be shown as color coded values (default) or as gray-scale.
- The scope functions allow to show some decided information about one single pixel or a selection of many pixels. A description about these information can be found in Chapter 5.1.5. The pixel selection can be deleted with right mouse click or by just doing a new selection.
    - “Pixelinfo“ allows to select a single pixel in the active live image by left mouse click. Current information about this pixel are shown in the decided information window (Fehler: Referenz nicht gefunden).
    - “Pixelscope“ shows the distance and amplitude values of a row of pixels (Fehler: Referenz nicht gefunden).
    - “Timescope“ shows a selection of an ROI in the live image. The ROI is defined with left mouse button. The average of distance and amplitude values over all selected pixels are shown against time axis (Fehler: Referenz nicht gefunden).
- “ROI“ selects a region of interest by using the left mouse buton. “Default ROI“ resets the ROI.

5.1.4. Point cloud

Live image window







5.1.5. Decided information windows

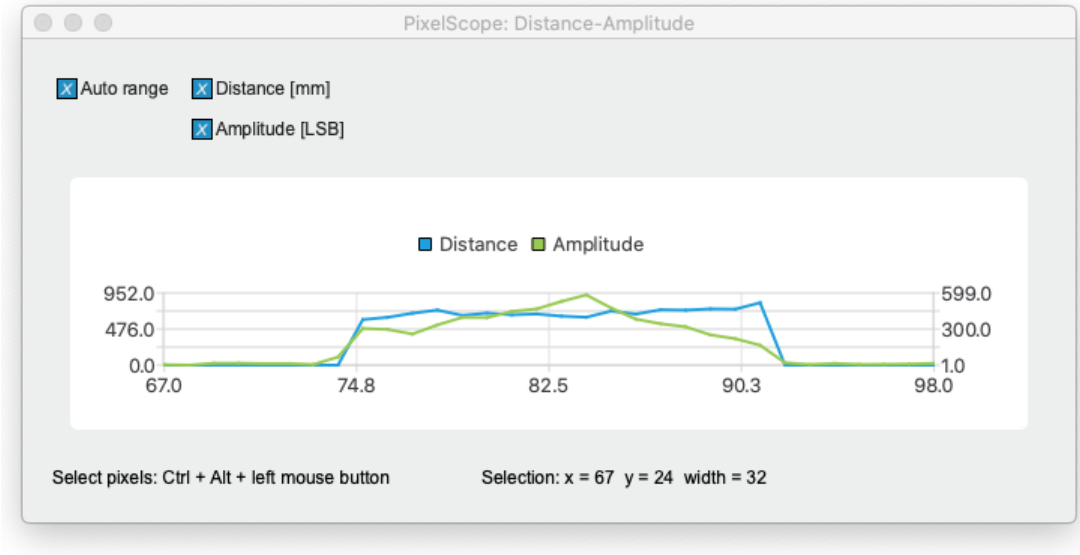


Figure 19: PixelScope window

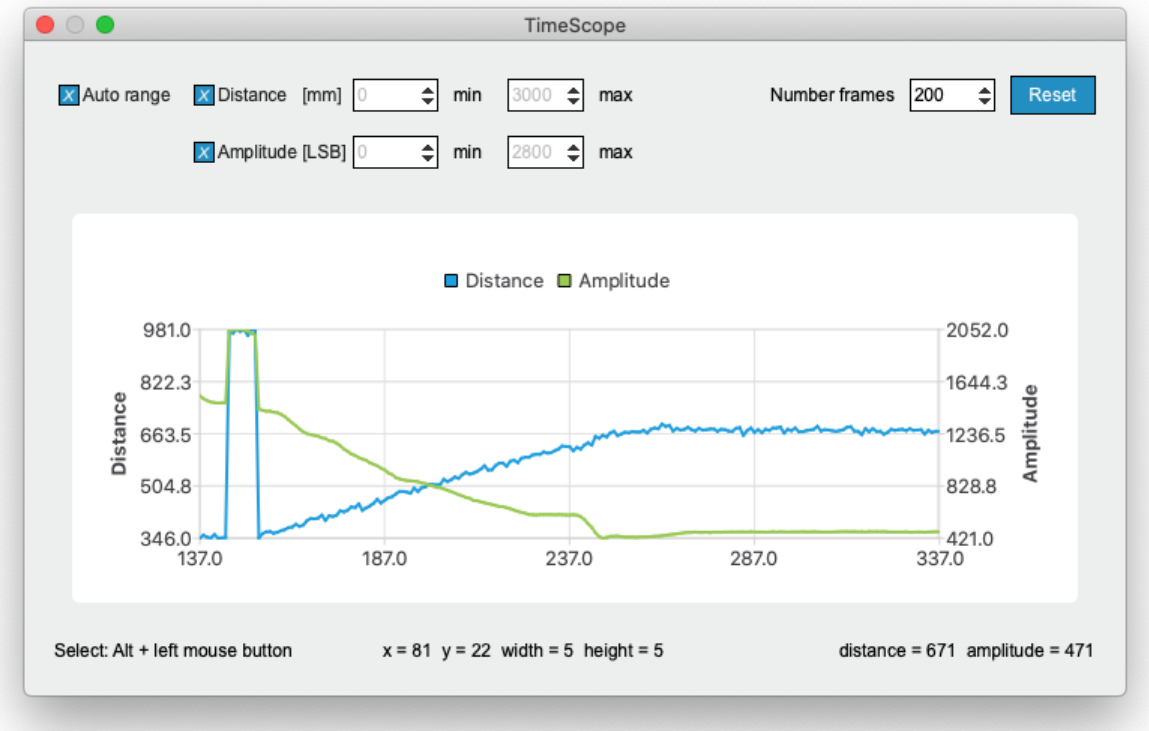
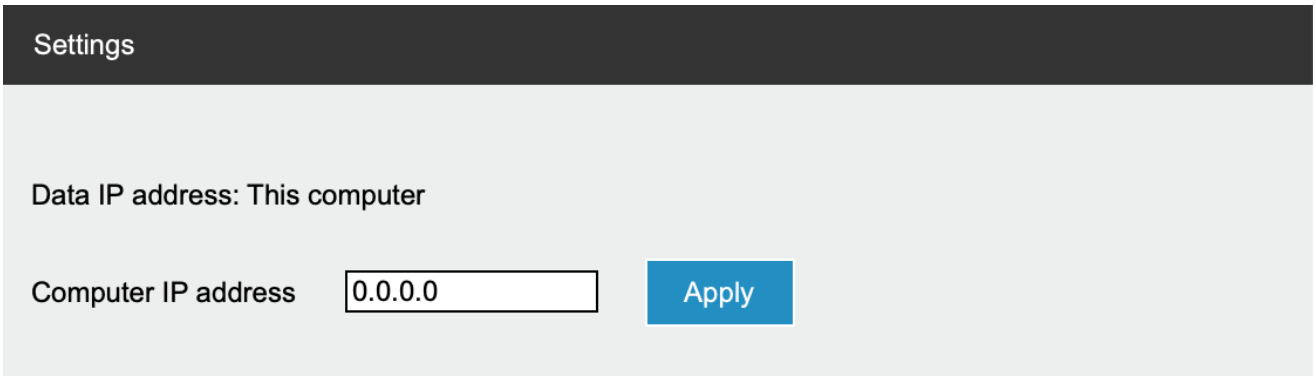


Figure 20: Time Scope window

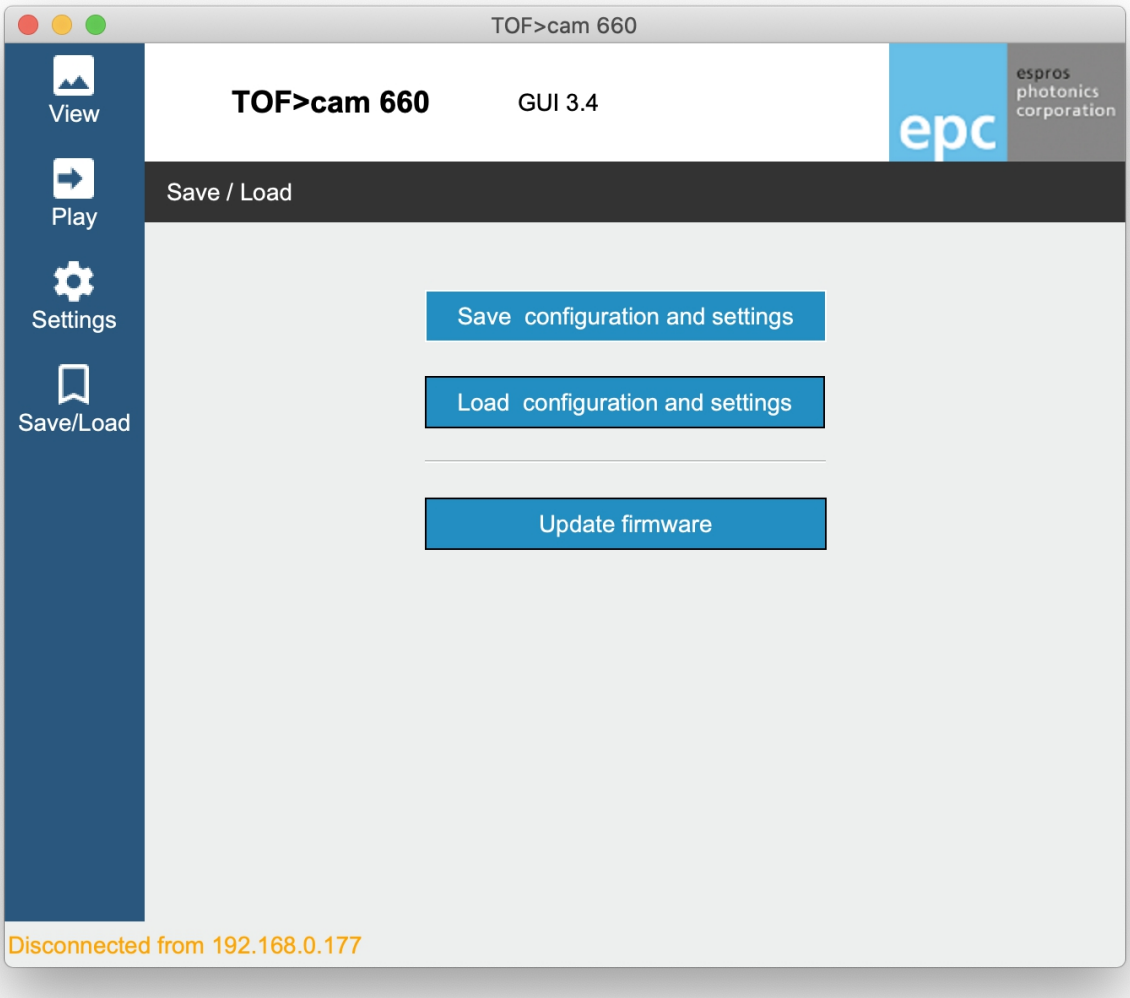
Number of frames can be used to compress or stretch time axis. With the “Reset“ function the current data can be deleted.

5.1.6. Settings

This IP adress set the path to the computer which receives the streaming data if this is different from the computer running the GUI. Refer to Chapter 5.1.1 how to start a data record to a different receiver.



5.1.7. Configurations menu



“Save configuration and settings“ to the PC.

“Load configuration and settings“ from the PC.

“Update firmware“ to the last firmware included in the GUI or to a manually selectable firmware file.

6. ROS camera driver

6.1. What is ROS?

The Robot Operating System (ROS) is a set of software libraries and tools that help you build robot applications. From drivers to state-of-the-art algorithms and with powerful developer tools, ROS has what is needed for a robotics project. It is all open source (Source: ROS.org). For more details, also refer to ROS.org and ROS Wiki sensors.

6.2. Installation

System requirement: Linux operating system.

Download the “ESPROS_TOFCAM660_SW_package” from the website www.espros.com, section Downloads, 02_Cameras_and_Modules.

There is enclosed the “ESPROS_TOFCAM660_ROS_driver” file. Unpack this ZIP file.

6.3. Running the ROS driver launch file

Change to the home directory and open the bash-file:

```
> cd ~
> gedit .bashrc
```

Insert the following line at the end of the bash-file:

```
source ~/projects/cam660_fpga_driver/devel/setup.bash
```

```
execute command:
> source ~/projects/cam660_fpga_driver/devel/setup.bash
```

Save the file and exit editor.

Start the ROS with GUI in terminal mode with the following command:

```
roslaunch espros_cam660_fpga camera.launch
```

The ROS tool opens with the different node windows and is ready to use.

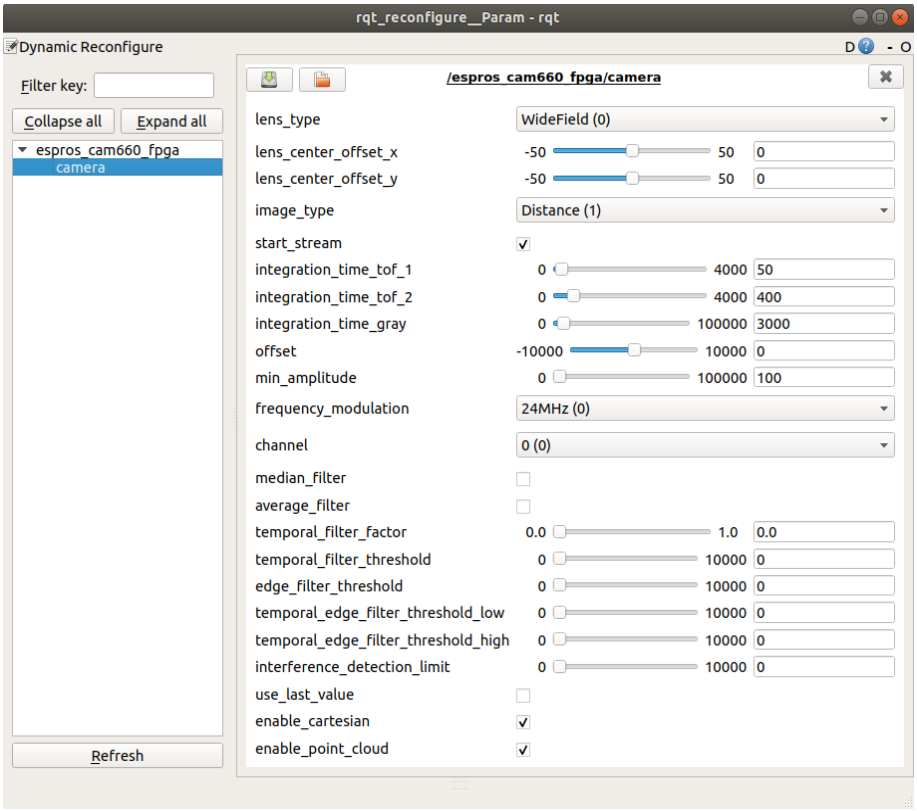


Figure 21: Example of the “dynamic reconfigure” node window

Start the camera operation by changing in the menu the parameter “start_stream” from false to true.

7. ROS API

This is the official driver for the ESPROS TOFcam660. The annotation follows the rules of ROS.org.

The ROS API was tested with these Linux & ROS configurations:

- Ubuntu 20.4 – Noetic
- Ubuntu 18.4 – Melodic
- Ubuntu 16.4 – Kinetic

7.1. Start of the node

If you use in terminal mode the APIs only, without GUI:
Start the ROS operating system in a Terminal with the command: `roscore&`
Start the TOFcam660 with the command: `rosrun espros_cam660_fpga cam660_fpga_node`

7.2. Published topics

Topic name	ROS msgs file	ROS message type	Function
camera/distance_image_raw	sensor_msgs	Image	Sends the grayscale or amplitude image according the selected image type parameter
camera/amplitude_image_raw	sensor_msgs	Image	Sends the distance image for image type parameters which include distance
camera/dcs_image_raw	sensor_msgs	Image	Sends 4 dcs images
camera/points	sensor_msgs	PointCloud2	Sends the point cloud image for image type parameters which include distance

Table 6: ESPROS ROS topics

7.3. Dynamically reconfigurable parameters

Refer for details on the dynamically reconfigurable parameters to the enclosed “dynamic_reconfigure package” or to http://wiki.ros.org/dynamic_reconfigure.

Parameter	Function	Data format	Default	Reference
~lens_type	Sets the lens field of view 0: WideField 1: StandardField 2: NarowField	int	0	n/a
~lens_center_offset_x	Sets the offset of lens center relative to sensor center Range: -50 … 50 pixels	int	0	n/a
~lens_center_offset_y		int	0	n/a
~image_type	Sets the image acquisition type 0: Grayscale 1: Distance 2: Distance and amplitude 3: DCS	int	1	n/a
~start_stream	Enables image streaming	bool	True	n/a
~integration_time_tof_0	Sets the integration time for distance measurements in microseconds. Range: 1 … 4'000 µs	int	50	n/a
~integration_time_tof_1		int	400	
~integration_time_gray	Sets the integration time for grayscale measurements in microseconds. Range: 0 … 50'000 µs	int	3000	n/a
~offset	Set distance offset. Range -10'000 … 10'000 mm	int	0	
~min_amplitude	Sets the amplitude limits. Range 0 … 2'047 LSB	int	100	
~frequency_modulation	Sets camera frequency modulation. Range: 24 … 0.75 MHz	int	0	n/a
~channel	Sets camera frequency modulation offset.	int	0	n/a
~spatial_median_filter	Enables the spatial median filter for distance filtering	bool	False	n/a
~spatial_average_filter	Enables the spatial average filter for distance filtering	bool	False	n/a
~temporal_filter_factor	Sets the factor 'k' of the temporal filter (Kalman). Range: 0.0 ... 1.0	double	0	n/a
~temporal_filter_threshold	Sets the threshold of the temporal filter (Kalman). Range: 0 ... 10000 mm	int	0	n/a
~edge_filter_threshold	Spatial edge filter threshold. Range: 0 … 10000 mm	int	0	n/a
~temporal_edge_filter_threshold_low	Temporal edge filter low threshold. Range: 0 … 10000 mm	int	0	n/a
~temporal_edge_filter_threshold_high	Temporal edge filter high threshold. Range: 0 … 10000 mm	int	0	n/a
~interference_detection_limit	Interference detection threshold. Range 0... 10000 mm	int	0	n/a
~use_last_value	Enables interference detection last value	bool	False	n/a
~enable_cartesian	Enables point cloud cartesian transformation (false = spheric)	bool	True	n/a
~enable_point_cloud	Activates pointCloud2Publisher node to send information (camera/points)	bool	True	Table1

Table 7: ROS parameter table

8. Maintenance and disposal

8.1. Maintenance

The device does not need any maintenance. A functional check is recommended each time the device is taken into operation:

- Check the mounting position and the detection area of the sensor with respect to the operational conditions. Also check that there is no hazardous situation.
- From time to time, clean the windows with a soft towel like you clean your sunglasses. Never use any solvents for cleaning. THE DEVICE CAN BE DESTROYED!

8.2. Disposal

Disposal should be done using the most up-to-date recycling technologies for electronic components according to the local regulations and laws. The design and manufacture of the cameras and components are done in compliance with the RoHS legal regulations. Traces of dangerous materials may be found in the electronic components, but not in harmful quantities.

9. Addendum

9.1. Related documents

Datasheet epc660, ESPROS Photonics Corp.

Book 3D-TOF, A guideline to 3D-TOF sensors that work by ESPROS Photonics Corp. (author Beat Dede Coi et. al.)

9.2. Links

www.espros.com

www.pointcloud.org - Point Cloud Library (PCL)

www.pdal.io - Point Data Abstraction Library (PDAL)

www.opencv.org - OpenCV (OpenSource Computer Vision)

www.ros.org - Robot Operating System (ROS)

http://wiki.ros.org - ROS documentation

9.3. Licenses

We appreciate the use of the following open source or free software in our tools and respect the large amount of work the owners have done:

Tool	Internet address	Licence holder
Qt-5	https://www.qt.io	Copyright (C) 2018 The Qt Company
ROS	www.ros.org	Open Source Robotics Foundation

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