## 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 offered 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.

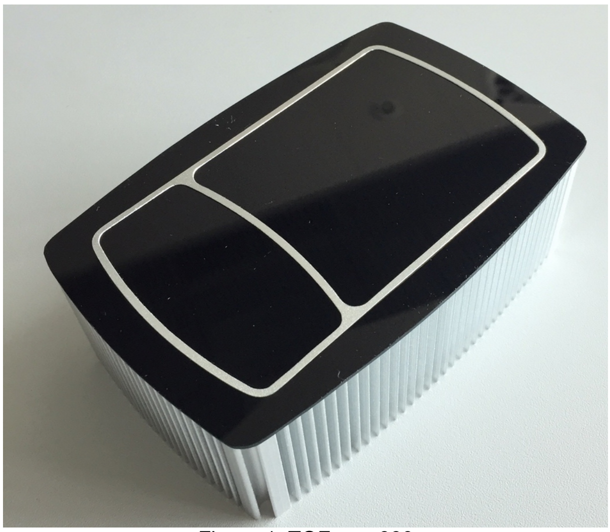


Figure 1: TOFcam-660

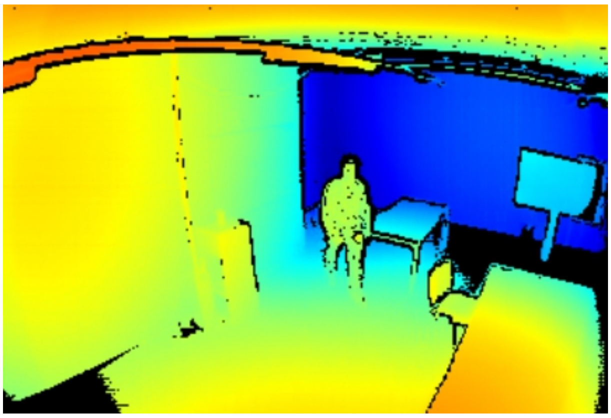


Figure 2: Color coded TOF distance

## 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
- Ethernet 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 a epc660 based TOF sensor
  - Automatic vehicle guidance, in-cabin monitoring
  - Object classification and safeguarding
  - Face recognition, Gesture control (man-machine-interface)

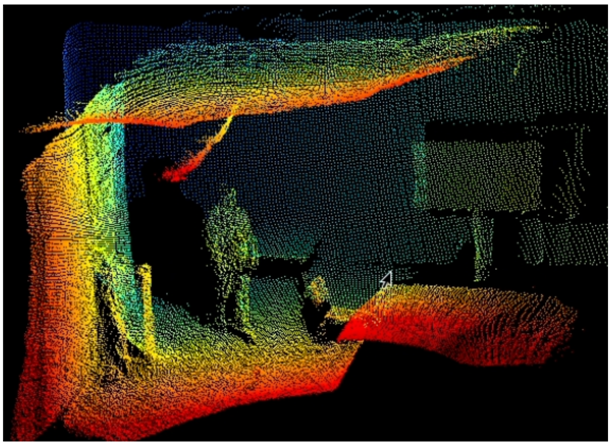


Figure 3: Point Cloud

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 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 data sheet 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 TOFCOS. Do not alter the TOFCOS 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<br>This camera should only be installed and used by authorized persons. All instructions in this data sheet 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 data sheets 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_SW_Package” containing a graphical user interface (GUI) for Windows, Mac or Linux computers, a robot operating system (ROS) application, and a Python API framework. The current firmware “TOFCOS” is part of the GUI which allows an easy upgrade of the camera with current firmware.<br>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) “TOFCAM660_SDK” containing all source codes of the firmware, GUI, ROS and API. Unpacking the SDK is password protected. Get back to ESPROS to check whether you fulfill 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 wave 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 |
| 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 |
| TOFCOS | Time of Flight Camera Operating System |
| 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.

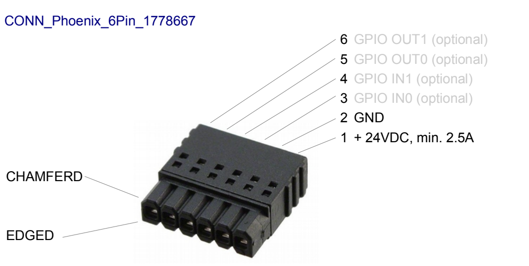



Figure 5: 6-pin power-supply and GPIO connector

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 visualization of data in the image window.

- 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.

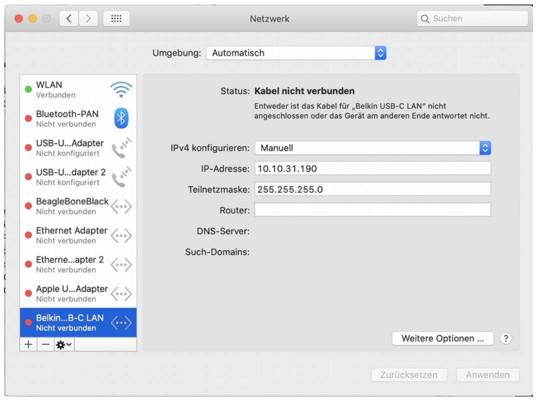



Figure 6: IP configuration of a USB-LAN adapter

## 3.2. Camera settings

- Choose Image Type “Distance“
- Select HDR mode “HDR temporal“ with integration times:
“low“ = 1000µs / “medium“ = 2000µs / “high“ = 4000µs
Depending on distance and reflectivity of the objects in the scene these values need to be reduced.
- For object detection set the "Minimum Amplitude" to 10 LSB, for accurate measuring to 100 LSB (this are good starting points, fine-tuning possible).
- Set the "Distance min" value to 100 mm and the “Distance max“ to the effective maximum distance in your scenery.
- Disable all Filter functions.
- Depending on the maximum distance in your field of view you should choose a suitable "Modulation frequency" (unambiguity). For long distance a low modulation frequency is required.
- If you choose a modulation frequency which is not 12 MHz (24 MHz e.g.) the camera is not calibrated. In this case it might be required to consider a corresponding offset.
- Start streaming with the “Start” button.
- Decrease the "Integration time 3D low" to a value where you get no ADC overflow (pink) or saturated pixels (purple). Adjust the integration time “medium“ and “high“ accordingly.
- 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 min" value.
- Change the image type to the illustration of the scenery you like to see.

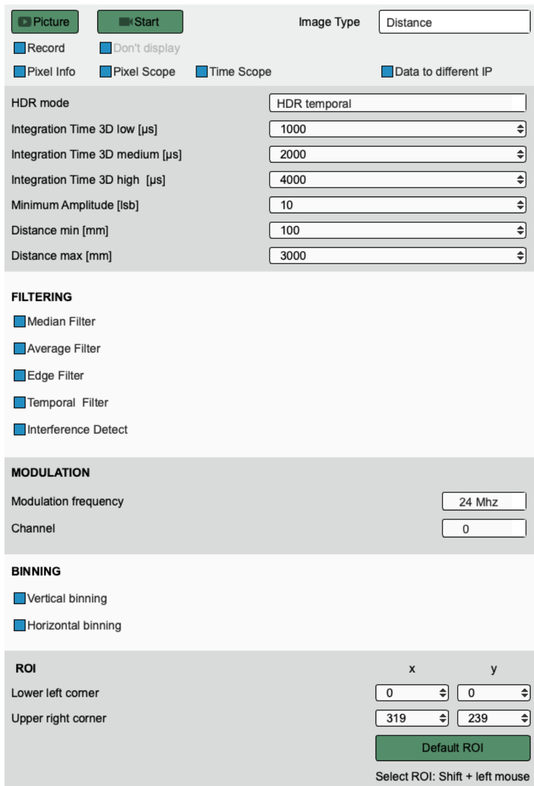



Figure 7: GUI window for camera settings

# 4. TOFcam-660 time of flight camera

## 4.1. System overview

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
- NXP I.MX RT1062 microcontroller
- The micro controller board communicates with the epc660 chip carrier board through an ultrafast TCMI serial interface.
- One out of four different 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 stray-light suppression for optimal optical performance
- LED illumination adopted to the specific field of view depending on the camera model
- TOF camera operating system (TOFCOS) for camera control, distance calculation and filtering
- Communication by Ethernet
- Application programming interface (API) for further processing is available. It opens the world for point cloud computing, using open source tools or creating own customer applications.
- ROS device drivers for Linux available
- Windows, Mac and Linux GUI available

## 4.2. Scope of delivery

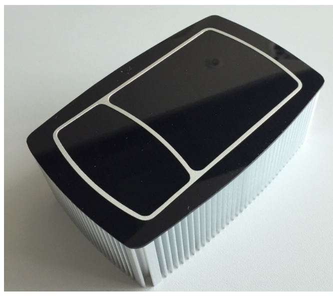
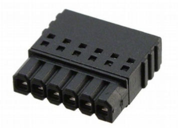
| Pieces | Part Name | Picture |
|---|---|---|
| 1 | Time of Flight Camera TOFcam-660 consisting of:<br>– Aluminum housing<br>– Receiver optic<br>– Illumination cpl.<br>– CPU electronics<br>– interfaces |  |
| 1 | 6 pin connector plug for 24V power supply and GPIO<br>– Plug with snap-fit clamps<br>–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

Table 2: Scope of delivery

## 4.3. Ordering information

| Picture | Part No. | Name | Description |
|---|---|---|---|
| | P100 654 | TOFcam-660-NF | FoV 31 x 24°, 81m operating range<br>50LSB on 18% reflective target at full sunlight |
| | P100 655 | TOFcam-660-SF | FoV 70 x 51°, 25m operating range<br>50LSB on 18% reflective target, up to 78kLux |
| | P100 656 | TOFcam-660-WF | FoV 108 x 77°, 11m operating range<br>50LSB on 18% reflective target at full sunlight |

| | | | |
|---|---|---|---|
| | P100 595 | TOFcam-660-UWF | FoV 125 x 93°, 6m operating range<br>50LSB on 18% reflective target |
| | P100 638 | 24VDC connector | Included in TOFcam-660 basic unit.<br>To connect the camera to a corresponding power supply. |
|  | P100 609 | Power adapter cable | Cable to connect a TOFcam-660 directly with the power supply P100 282 |
|  | P100 282 | Power Supply 24VDC | Input 100 … 240V<br>DC output: 24V, 2.5A |
|  | P100 284 | Power cord 2 pole | CH/EU plug |
|  | P300 189 | Power cord adapter<br>CH/EU - US | |
|  | P300 780 | Patch cable, 2m, RJ45 | |
|  | P300 781 | Adapter RJ45 to USB | |
| | P300 473 | Cable USB A to Micro USB | |

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. | Typical | 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 | | ° | |
| | | Version UWF | | 125 x 93 | | ° | |
| $D_R$ | Measuring range in dark | Version NF | 0.5 | | 96 | m | 2% accuracy on 90% reflective target, dark |
| | | Version SF | 0.3 | | 38 | m | |
| | | Version WF | 0.2 | | 18 | m | |
| | | Version UWF | 0.2 | | 12 | m | |
| $D_M$ | Measuring range on full sunlight | Version NF | 0.5 | | 38 | m | 2% accuracy on 90% reflective target, 100kLux ambient light |
| | | Version SF | 0.2 | | 10 | m | |
| | | Version WF | 0.2 | | 5 | m | |
| | | Version UWF | 0.2 | | 4 | m | |
| Acc | Accuracy, measuring range min. … 2m | | | ± 4 | | cm | Mean of 100 samples |
| | Accuracy, 2m … measuring range max. | | | ± 2 | | % | |
| $f_{MOD}$ | Modulation frequency selectable | | 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 | | - $f_{MOD}$ / 34 approx. | | 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 | | + $f_{MOD}$ / 34 approx. | | 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. | Typical | 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 | |
| $\Phi_{AL}$ | 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 | | | 600 | | g | Without cable |
| ESD | Electrostatic discharge rating | | JEDEC HBM class 1C (1kV to < 2kV) | | | | Human body model |
| EMC / EMI | EMC emission | | EN 61000-6-3:2011-09 | | | | |
| | Eye safety | | IEC 62471:2006 | | | | 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.

3 To reliably avoid interference in multi camera applications the effective modulation frequency of the selected channels should differ for at least 50 kHz between each single unit. Thus at modulation frequencies lower than 12 MHz not all channels should be used.

## 4.5. Mechanical data

### 4.5.1. Mechanical features

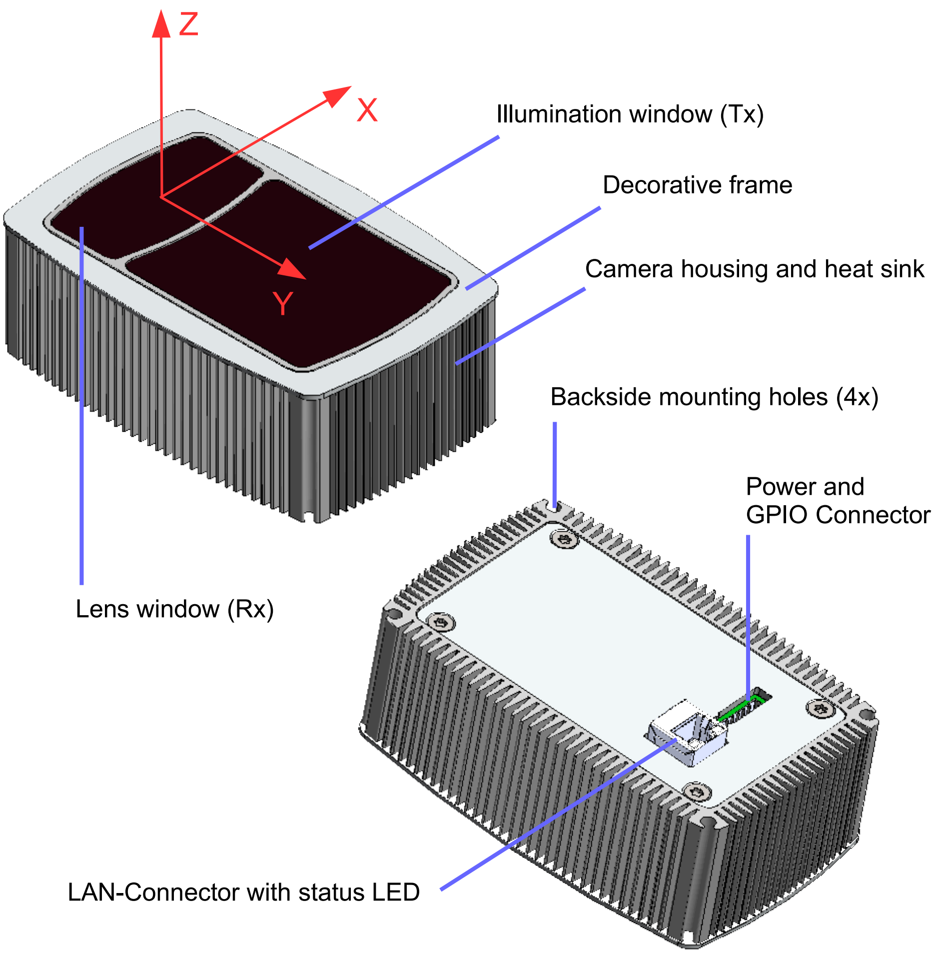



Figure 8: Mechanical features

#### 4.5.2. Mechanical dimensions

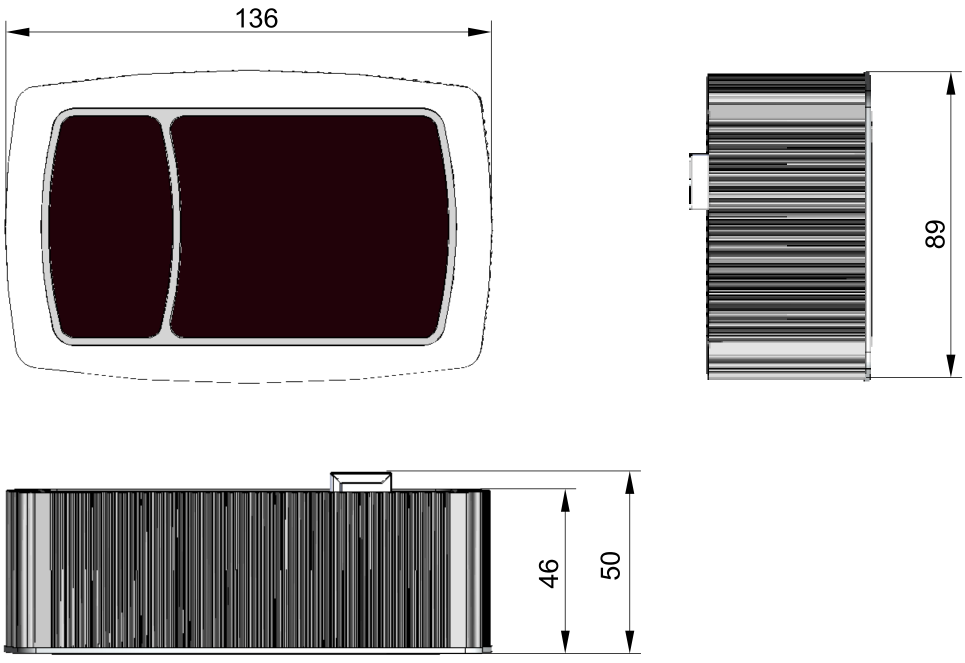



Figure 9: Camera dimensions

## 4.6. Camera connectors

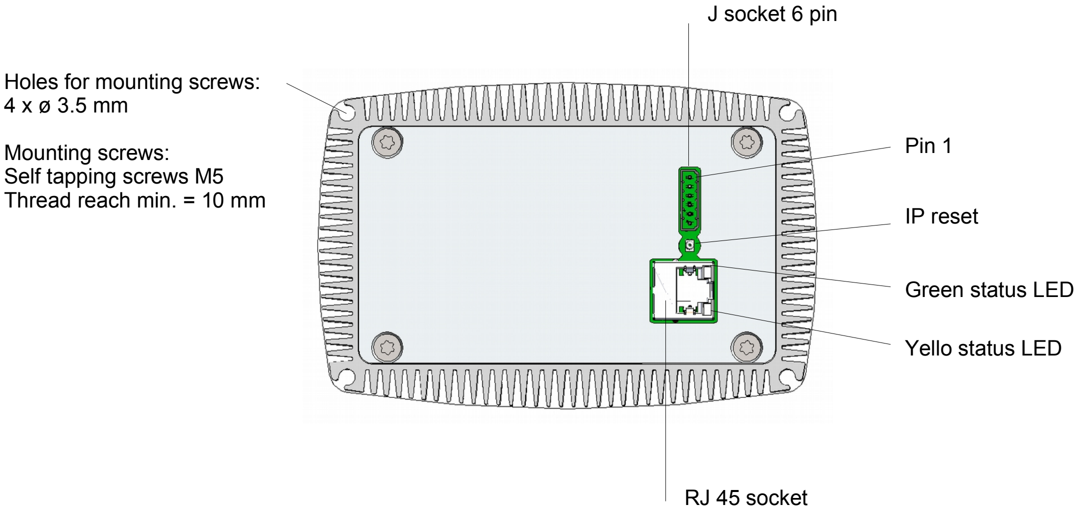



Figure 10: Camera connectors

#### 4.6.1. LAN connector

| | |
|---|---|
| Connector type: | THD Connector RJ45, 8P8C 1000BASE-T |
| Matching plug: | any RJ45 8P8C plugs |
| Accessory: | LAN cables and Ethernet to USB adapter available 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 input, refer to toFigure 11 |
| 4 | PIN4 | IN 1 | |
| 5 | PIN5 | OUT 0 | Digital output, refer toFigure 12 |
| 6 | UART_TX | OUT 1 | |

Table 5: Pin table

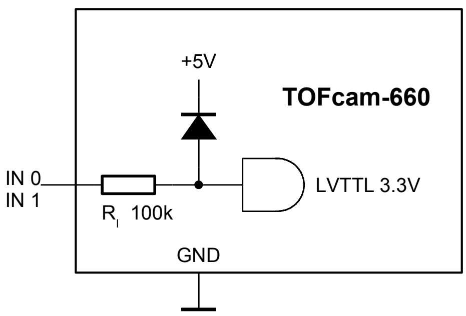



Figure 11: Input pins IN 1 and IN 2

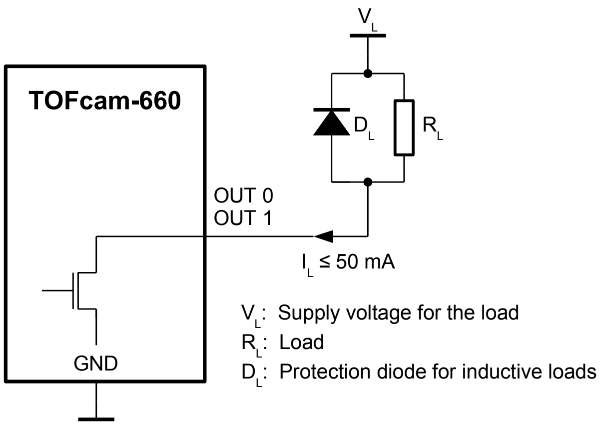



Figure 12: Output pins OUT1 and OUT2

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

#### 4.6.3. IP reset button

If you get no connection to a TOFcam-660 with changed and unknown IP address the IP reset button allows you to reset the IP to factory standard of 10.10.31.180. Therefore press the button for 5 seconds during start-up of the camera.

## 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 visualization in the image window. In most cases you need to disable the firewall or to set an exception for the camera application.

- Connect your camera directly with your computer using a RJ45 patch-cable or additionally using a 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 light 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 “Start” a data stream do not open an image window then the firewall blocks the application or the LAN has too low transfer rate.

## 4.8. Firmware upgrade

To upload the firmware over ethernet you need to do the following steps:

1. Click the “Update firmware” button in GUI, refer to Chapter 5.3

   or

   Send command “JUMP_TO_BOOTLOADER“, open a new browser-window and type the current IP of the TOFcam-660 into the address line of the browser

2. Erase the current camera application. You need to confirm the deletion using the password TOFcam-660

3. Choose the update file (usually “cameraApplication_XiP.bin“) by browsing your harddisk. The firmware according GUI release date is included in the folder “firmware” included in “TOFCAM660_SW_Package” from the ESPROS download page.

4. Start the firmware upgrade process with the “Upload“ button.

5. Start the TOFcam-660 to check whether the firmware upgrade was successul.

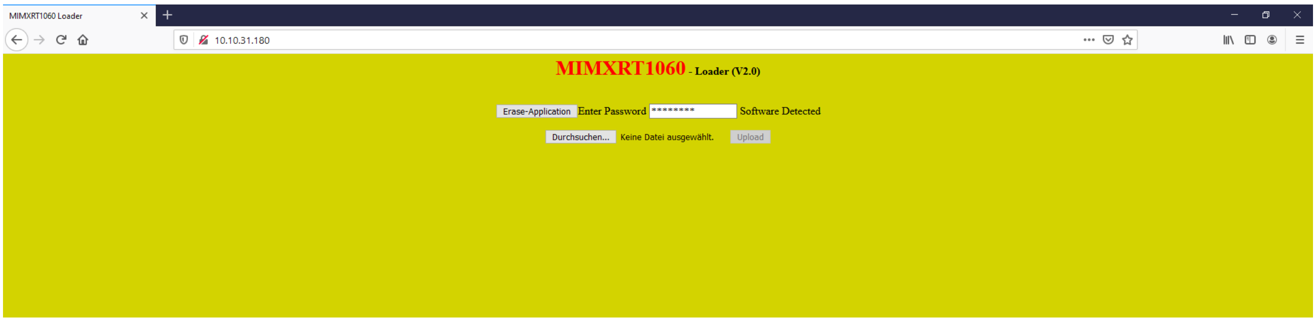



Figure 13: Figure 11: Browser based bootloader tool

# 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 “TOFCAM660” 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.

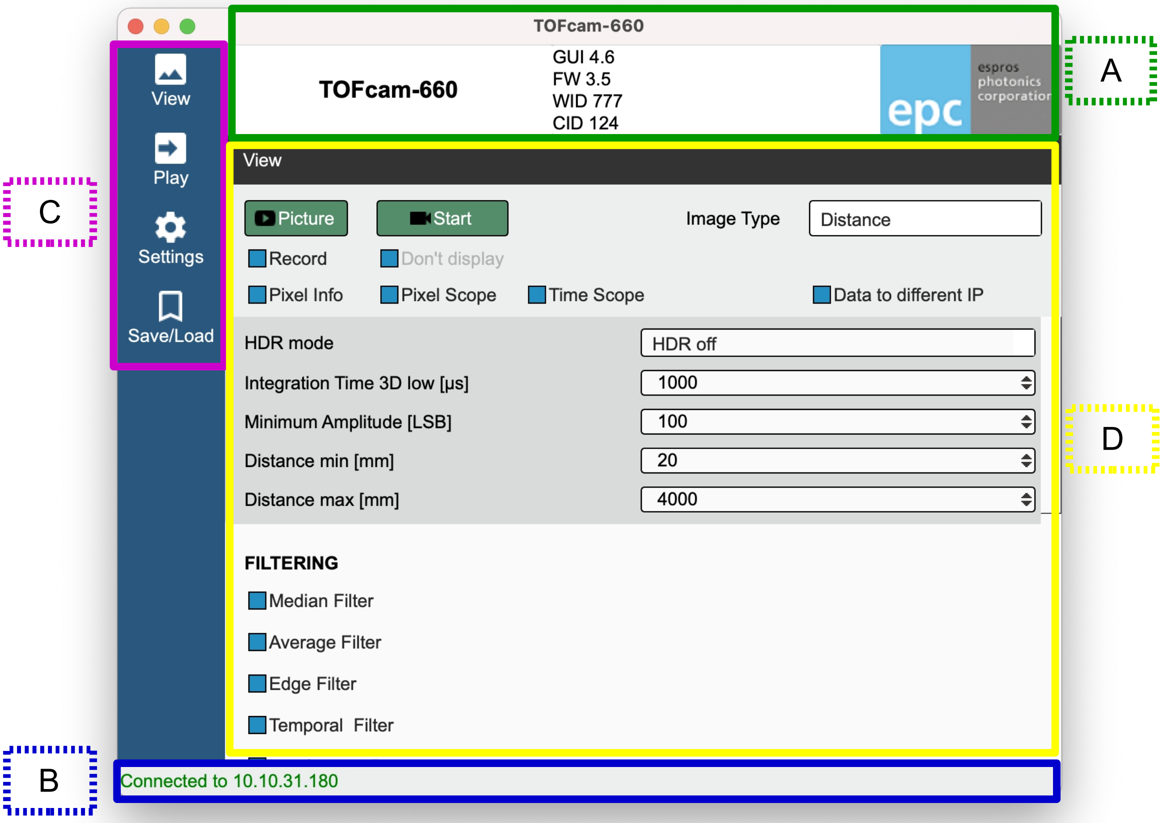



Figure 14: Sections of the GUI main screen

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

B) Connection status:

C) Menu tab

| | |
|---|---|
| View | Chapter 5.1.1 |
| Play | Chapter 5.1.2 |
| Settings | Chapter 5.2 |
| Save/Load | Chapter 5.3 |

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, DCS (raw data) or point clouds can be captured, streamed or recorded. Detailed information about pixel groups or one single pixel can be illustrated. For the whole GUI there are helpful tooltips available. These tooltips pop-up by moving the cursor either to the corresponding text (refer to Figure 16).

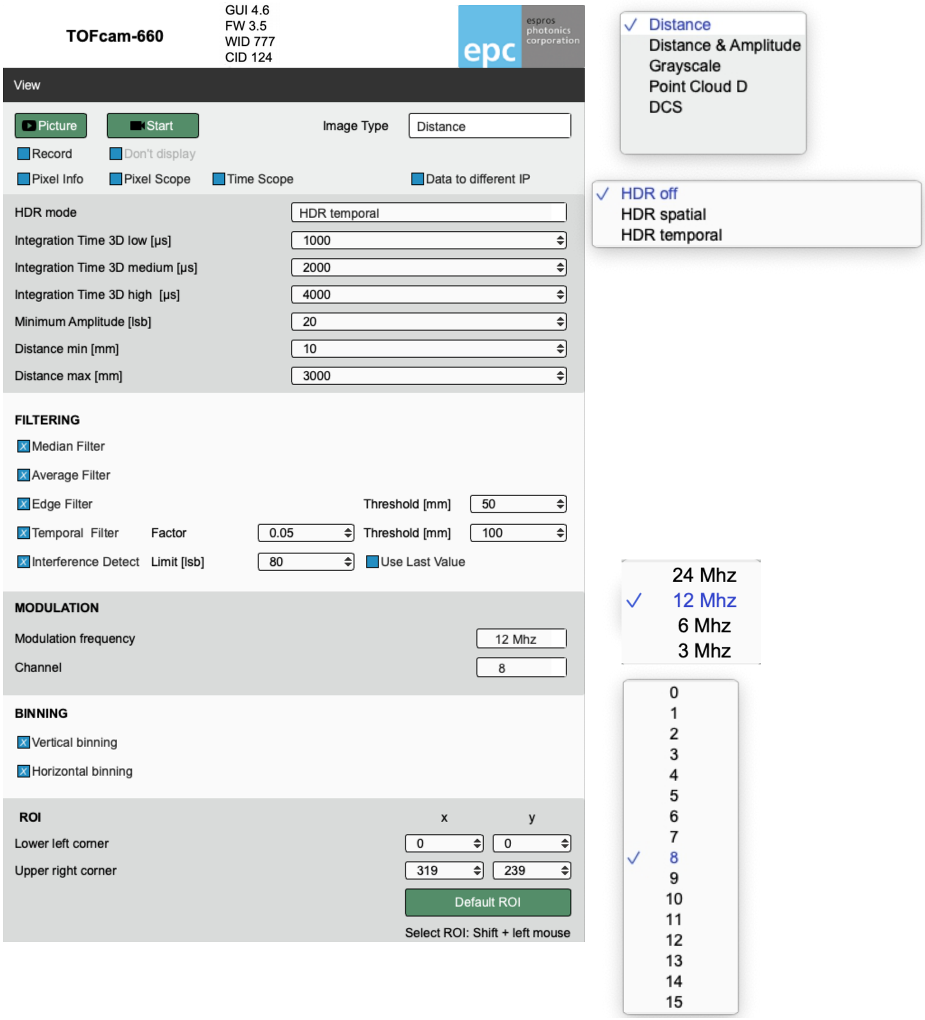



Figure 15: Camera controls

- “Picture“ and “Start“ open the “Image“ window according to the selection in the “Image Type” drop-down menu. Please see Chapter 5.1.4 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 one which controls the camera.
- The “Info” and “Scope” check boxes open additional windows with dedicated information. You will find additional description about these functions in Chapter 5.1.6.
- “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 low“ value and all even rows with the “Integration Time 3D medium“ value.
- “HDR temporal“ allows using up to 3 different integration time values (integration times with zero values are ignored). In this mode one complete image is acquired with each set integration time 3D low … high. After the acquisition of all frames, a new image is generated from the different frames by using the most confident value (pixel by pixel). Due to multiple image acquisitions, 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.
- 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 De Coi et. al.).
- “Distance min“ cuts off all pixels reporting a value below this setting. In addition, the color distance minimum scale is adjusted to this setting.
- “Distance max“ cuts off all pixels reporting a value beyond this setting. In addition, the color distance maximum scale is adjusted to this setting.

- The color scale visualizes distance of every pixel in the viewer. Dark red represents the shortest, dark blue the farthest distances.
- Various powerful filter functions are available with specific thresholds and filter factors. The algorithms behind are shown in corresponding tooltips.
- 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” selection allows a shift of the modulation frequency from 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 or channel respectively. The difference of the effective modulation frequency of the cameras used should be at least 50 kHz. Refer to Chapter 4.4
- Vertical and horizontal binning allow to combine two neighbor pixels each to one single value. Due to the higher signal level the noise will be reduced and distance accuracy increased. The resolution will be reduced by factor two each.
- 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 320 x 240 pixels.

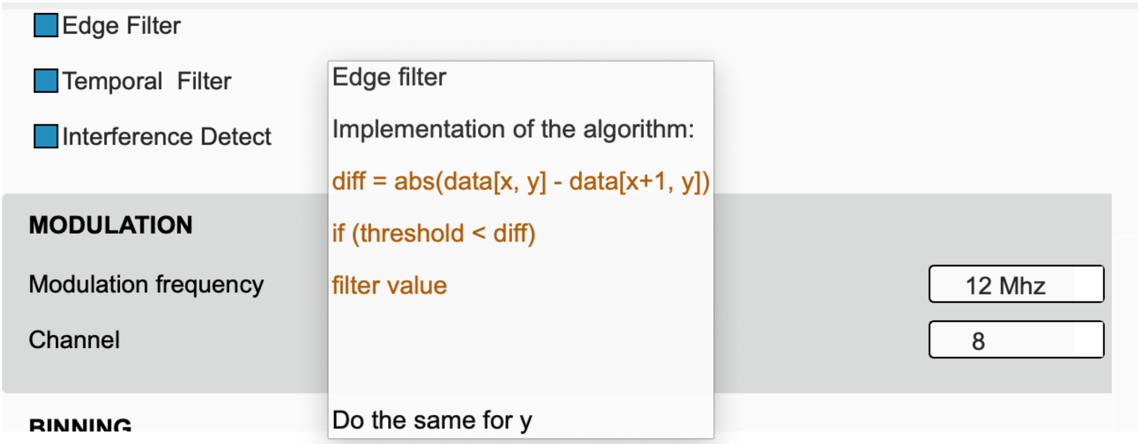



Figure 16: Tooltip examples

#### 5.1.2. Play menu

The “Play“ menu allows replaying the recorded streams. This is possible in slow motion, original speed or accelerated. A single frame can be searched and selected and the streamed data can be converted to point clouds. This functions of the GUI can be used even if no camera is connected.

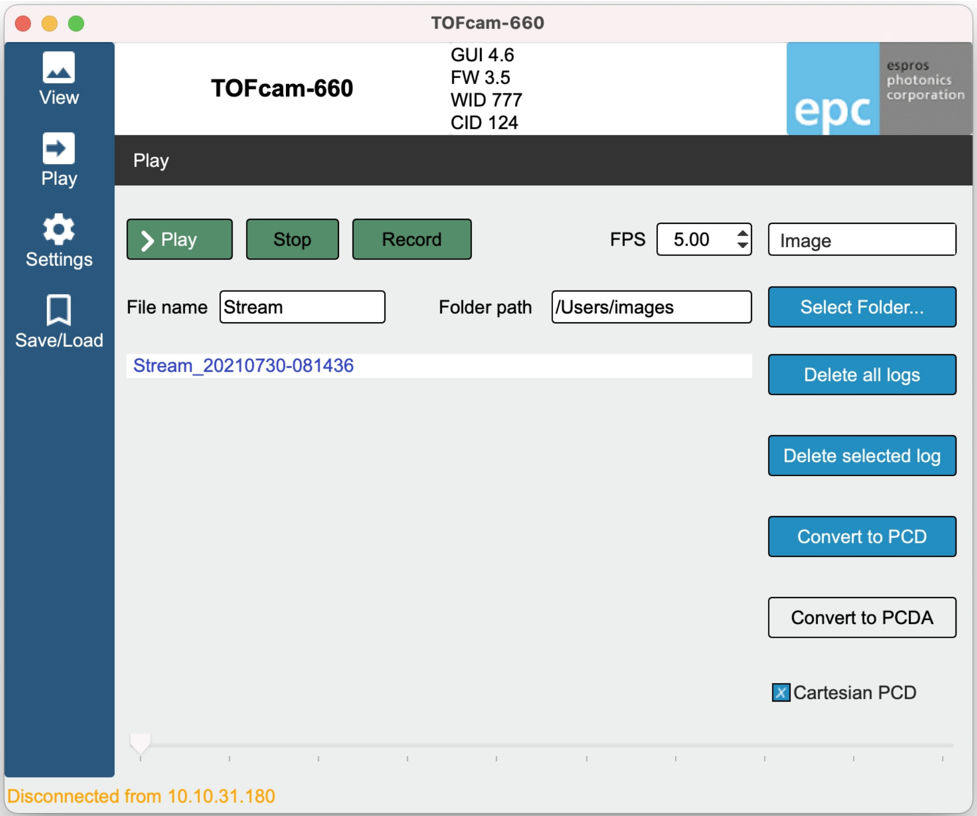



Figure 17: Player controls

- “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 5.1.1.
- “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. This 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“ allows converting the recorded binary files to point cloud files which are compatible with point cloud applica-tions such as “Cloud Compare“ or “Cloud Compare Viewer“. The converted 3D point cloud has a distance color coding or an amplitude color coding (“Convert to PCDA”).
- The slide bar in the bottom allows manual spooling of the stream forth and back.

#### 5.1.3. Streaming files format description

Images are recorded in selected folder and consists of 2 type files:
A) index ASCII file - <file name>_<yyyymmdddd>-<hhmmss>.idx
B) binary data files - <file name>_<yyyymmdddd>-<hhmmss>-<index>.bin

Index .idx file contains binary file names in ASCII format.
Image .bin files contains image information in binary format, are using LittleEndian coding and consist of 4 parts:
1. Image header - 25 bytes.
2. User data – optional (comments and addition information. By default no user data).
3. Data – ROI (width * height) * 2 or ROI (width * height )* 4 (2 bytes per pixel).
4. Additional recorder information - 3 bytes.

BIN image format:
file size - 4 bytes
VERSION - 1 byte
DATA_TYPE - 2 bytes
WIDTH - 2 bytes
HEIGHT - 2 bytes
ROI_X0 - 2 bytes
ROI_Y0 - 2 bytes
ROI_X1 - 2 bytes
ROI_Y1 - 2 bytes
INT_TIME0 - 2 bytes
INT_TIME1 - 2 bytes
INT_TIME3 - 2 bytes
TEMPERATURE - 2 bytes
OFFSET - 2 bytes (information were begins image data)
USER_DATA – x bytes (offset - 25)
DATA - x bytes (from offset)

TIME_DIFF – 2 bytes (time stamp difference mS)
DEVICE_ID – 1 byte (5 for cam660)

Data:
for distance image: (2 bytes ) x width x height - 2 bytes per pixel
for amplitde-distance image: (amplitude 2 bytes + distance 2 bytes ) x width x height - 4 bytes per pixel

#### 5.1.4. 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. This window contains the images according to the selected “Image Type“. A recorded stream contains only the data which has been selected during the recording process (distance, amplitude, grayscale or DCS raw data).

With several controls the image can be adjusted to users needs: mirror and rotation functions to adjust the image according to the camera installation position and direction of view, region of interest and all info and scope functions with dedicated information as described in Chapter 5.1.6.

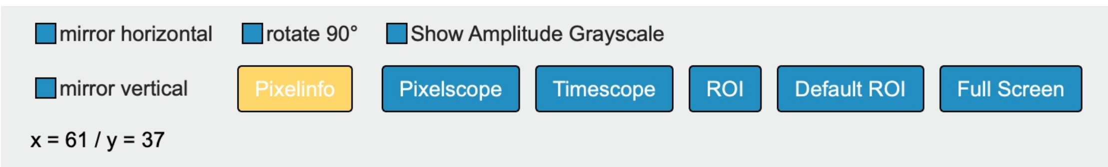



Figure 18: Live image controls

- “mirror horizontal“ flips the image horizontally.
- “mirror vertical“ flips the image vertically.
- “rotate 90°” rotates the image for 90°.
- 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 5.1.6. The pixel selection can be deleted with right mouse click or by just doing a new selection.
- “ROI“ selects a region of interest by using the left mouse button. “Default ROI“ resets the ROI.
- “Full screen“ fits the live image window to the screen. To leave the full screen mode press “Esc“.

### 5.1.5. Point cloud

The “Point cloud” window pops-up after a streaming, a replay or a recording has been started from the “View“ or the “Play“ menu with image type “Point cloud“.

The point cloud can be adjusted according to the camera installation position and direction of view with the mirror and rotation functions. Using the control buttons for default, front, side and top view turns the point cloud into a well defined direction.

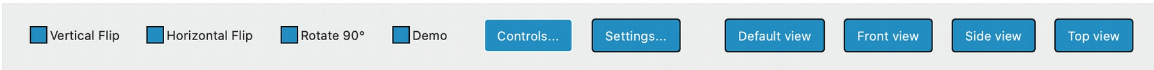



Figure 19: Point cloud window

Using keyboard and mouse allows further controls of the point cloud illustration. Activating the “Settings“ allows additional fine tuning of the point cloud visualization.

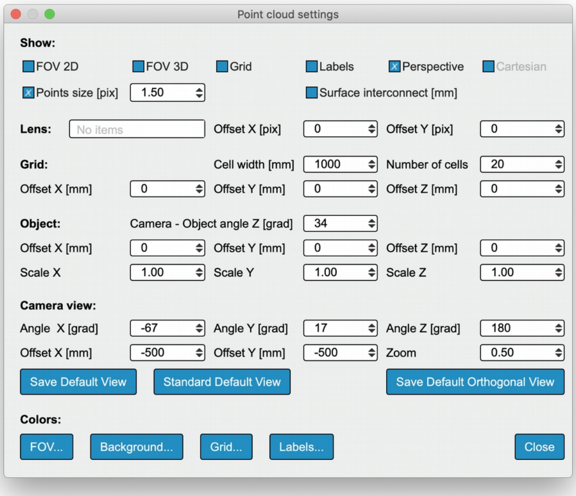



Figure 20: Point Cloud Settings

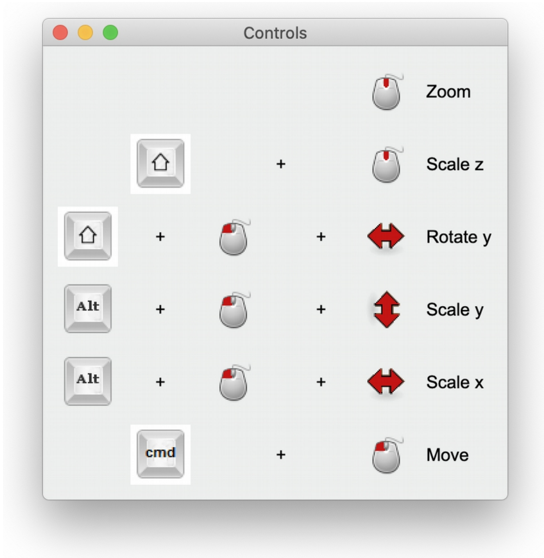



Figure 21: Point Cloud Controls

### 5.1.6. Selective information windows

Pixel data shows the distance values and confidence level of one selected pixel. Minimum, Maximum and Average values from the last 100 measurements as well as standard deviation are shown. Additionally the current frame rate and the chip temperature (temporally filtered) are indicated.

The pixel scope shows the current values of a selected row or an area of selected pixels where each column is indicated separately and all pixels per column are averaged.

The time scope is used to plot the chronologic distance and / or amplitude values of a single pixel or a averaged values of a selected area of the pixel field.

“CopyToClipboard” and “Save” allows to use the current content of the scope fur further use as spreadsheet.

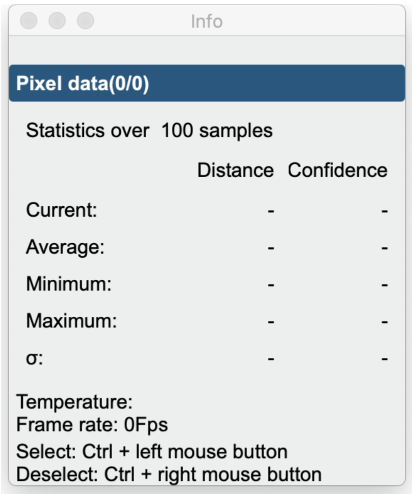



Figure 22: Pixel data

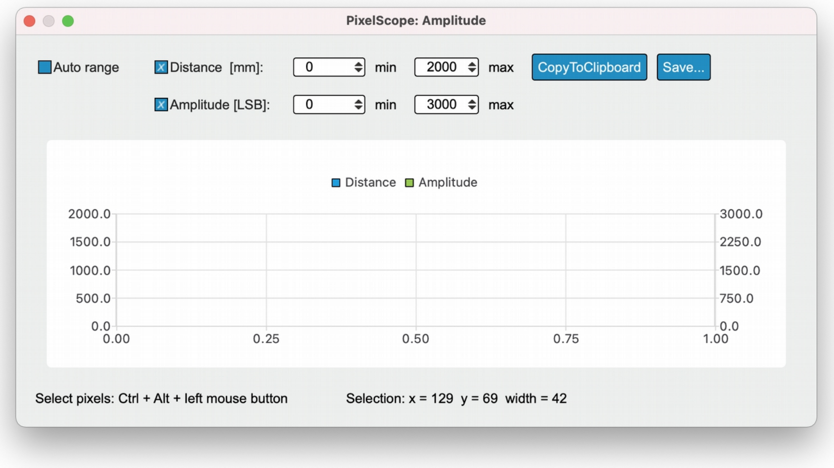



Figure 23: Pixel Scope

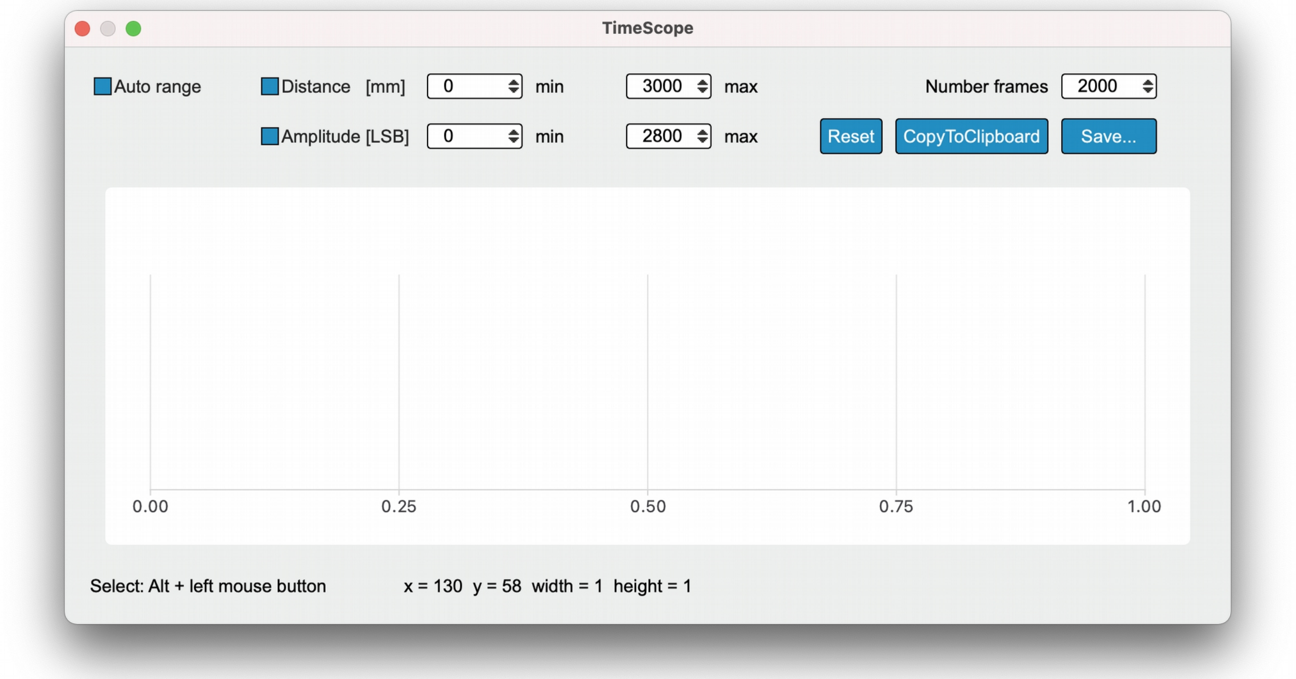



Figure 24: Time Scope

## 5.2. Network settings

It is possible to change the IP address, subnet mask and the gateway of the camera. “Apply IP” permanently stores the current network settings of the TOFcam-660 currently connected.
If the network settings have been changed accidentally it is possible to reset these values to factory settings. Please refer to Chapter 4.6.3 how to do that.

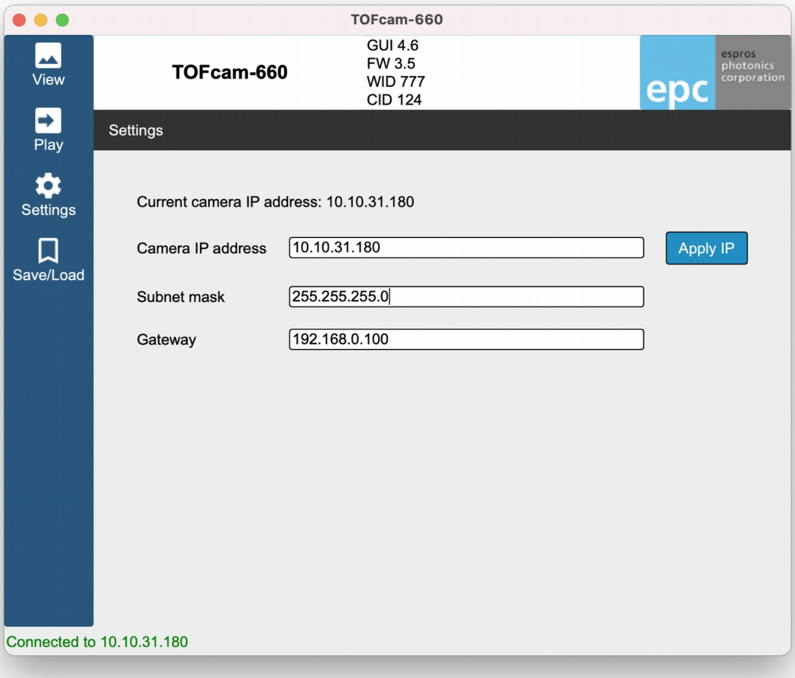



Figure 25: Network settings

## 5.3. Configurations menu

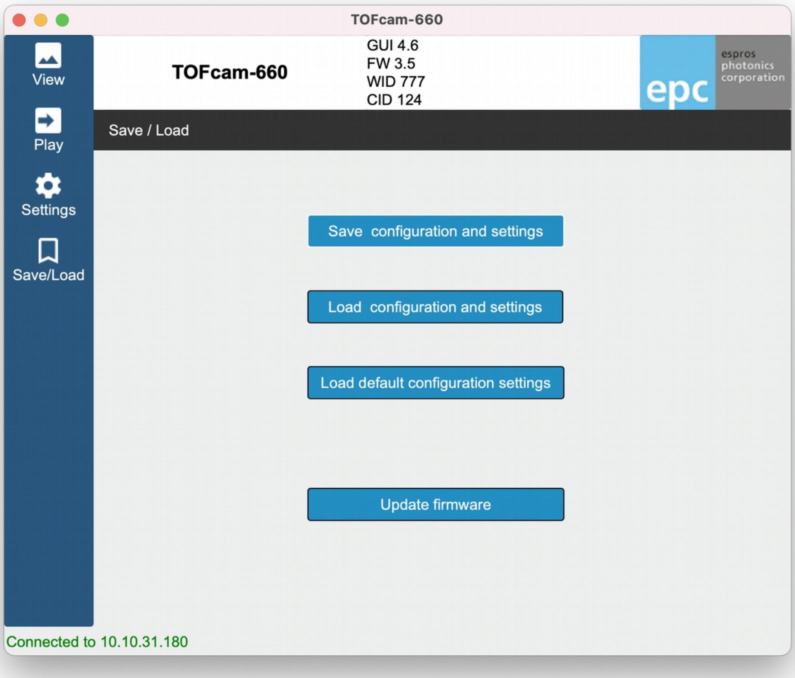



Figure 26: Load and safe camera configurations

“Save configuration and settings“ from the current camera application to a file.

“Load configuration and settings“ from a file stored on the PC into the camera application.

“Load default configuration settings” restores all factory set default values.

“Update firmware” allows to upgrade the firmware according to Chapter 4.8

# 6. Operating the device with a ROS

## 6.1. ROS camera driver

### 6.1.1. 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.

### 6.1.2. Building the ROS driver

System requirement: Linux operating system.

Download the “TOFCAM660_SW_Package” from the website www.espros.com, section Downloads, 02_Cameras_and_Modules.

There is enclosed the “TOFCAM660_ROS_driver” file.

Extract zip file for example in `~/projects/` directory

Change current directory:

```
> cd ~/projects/cam660_driver
```

Build a project from the command:

```
> catkin_make
```

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_driver/devel/setup.bash
```

Save the file and exit editor.

Log-out and again log-in linux or execute command:

```
> source ~/projects/cam660_driver/devel/setup.bash
```

### 6.1.3. Running the ROS driver with launch file

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

```
roslaunch espros_tof_cam660 camera.launch
```

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

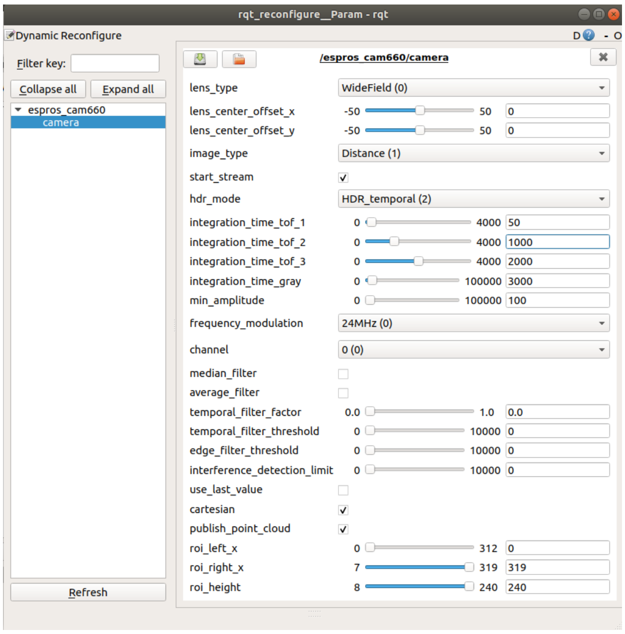


Figure 27: Example of the “dynamic reconfigure“ node window

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

## 6.2. ROS API

This is the official driver for the ESPROS TOFcam-660. The annotation follows the rules of ROS.org.

### 6.2.1. Start of the node

If you use in terminal mode the APIs only, without GUI:
Start the ROS operating system in a Terminal1 with the command: `roscore`
Start the TOFcam-660 in a Terminal2 with the command: `rosrun espros_cam660 cam660_node`

### 6.2.2. 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

#### 6.2.3. 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<br>0: WideField<br>1: StandardField<br>2: NarrowField | int | 0 | n/a |
| ~lens_center_offset_x | Sets the offset of lens center relative to sensor center<br>Range: -50 … 50 pixels | int | 0 | n/a |
| ~lens_center_offset_y | | int | 0 | n/a |
| ~image_type | Sets the image acquisition type<br>0: Grayscale<br>1: Distance<br>2: Distance and amplitude<br>3: DCS | int | 1 | n/a |
| ~start_stream | Enables image streaming | bool | True | n/a |
| ~hdr_mode | Sets HDR mode<br>0: hdr off<br>1: hdr spatial<br>2: hdr temporal | int | 0 | n/a |
| ~integration_time_tof_1 | Sets the integration time for distance measurements in microseconds. Range: 1 … 4'000 µs | int | 50 | n/a |
| ~integration_time_tof_2 | | int | 400 | |
| ~integration_time_tof_3 | | int | 1000 | |
| ~integration_time_gray | Sets the integration time for grayscale measurements in microseconds. Range: 0 … 50'000 µs | int | 3000 | n/a |
| ~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 |
| ~median_filter | Enables the spatial median filter for distance filtering | bool | False | n/a |
| ~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).<br>Range: 0.0 ... 1.0 | double | 0 | n/a |
| ~temporal_filter_threshold | Sets the threshold of the temporal filter (Kalman).<br>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 |
| ~cartesian | Enables point cloud cartesian transformation (false = spheric) | bool | True | n/a |
| ~publish_point_cloud | Activates pointCloud2Publisher node to send information (camera/points) | bool | True | Table 6 |
| ~roi_left_x | Sets ROI (region of interest) left x position. Range 0 … 312 | int | 0 | n/a |
| ~roi_right_x | Sets ROI (region of interest) right x position. Range 7 … 319 | int | 319 | n/a |
| ~roi_height | Sets ROI (region of interest) height. Range 8 … 240 | int | 240 | n/a |

Table 7: ROS parameter table

# 7. Communication interface

## 7.1. Description

The TOFcam-660 is connected to a PC. The TOFcam-660 acts as TCP server: one TCP connection and one UDP connection are opened for command and measurement data as shown in Figure 29. A simple command/answer structure is used: the PC sends a command to the camera and the camera answers it with an acknowledge or an error code over the command connection. A soon as the requested data is ready it is sent over the measurement connection. The data is marked with marker bytes for handshaking The following ports are used for communication:

- TCP commands connection: 50660
- TCP trace information: 50661
- UDP measurement data connection: 45454

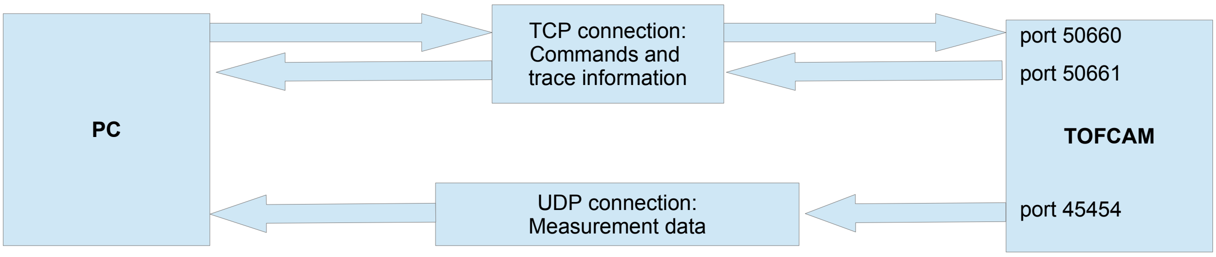



Figure 28: TOFcam-660 host interface

## 7.2. Command Connection (TCP)

| | | | |
|---|---|---|---|
| start marker<br>4 Bytes<br><br>0xFFFFAA55 | PayloadSize<br>4 Bytes | Payload<br>1 ... XXX Bytes | end marker<br>4 Bytes<br><br>0xFFFF55AA |

Figure 29: Command/Answer packet composition

Command and answer packets are composed from fields as shown in Figures 29 and . With the marker bytes and the size a reliable detection of the packet boundaries can be achieved.

The payload itself is composed of the following fields:

| | | |
|---|---|---|
| Command<br><br>2 Bytes | Parameters/data size depending on command, see Chapter 8.1 | User data:<br><br>0 … 1024 Bytes |

Figure 30: Command payload fields

| | | |
|---|---|---|
| Answer<br><br>1 Byte | Parameters/data size depending on answer, see Chapter 8.2 | User data:<br><br>0 … 1024 Bytes |

Figure 31: Answer payload fields

User data: Meta-data that will be returned in the measurement data (UDP). Can be used to identify the data.

# 8. Communication

## 8.1. Commands

<table>
<tr><th>Command</th><th>ID</th><th>Parameters</th><th>Description</th></tr>
<tr><td rowspan="2">SET_ROI</td><td rowspan="2">0<br>(0x00)</td><td>X0: 2Bytes<br>Y0: 2Bytes<br>X1: 2Bytes<br>Y1: 2Bytes</td><td>Set the ROI of the sensor<br>default:<br>x0,Y0 = 0<br>x1 = 319<br>y2 = 239</td></tr>
<tr><td colspan="2">Example:
<table>
<tr><td>ID</td><td colspan="2">X0</td><td colspan="2">Y0</td><td colspan="2">X1</td><td colspan="2">Y1</td></tr>
<tr><td>0x00</td><td>0x00</td><td>0x00</td><td>0x00</td><td>0x00</td><td>0x01</td><td>0x3F</td><td>0x00</td><td>0xEF</td></tr>
</table>
X0 = 0, Y0 = 0, X1 = 319, Y1 = 239</td></tr>
<tr><td rowspan="2">SET_INT_TIMES</td><td rowspan="2">1<br>(0x01)</td><td>IntegrationTime3DLow: 2Bytes (< 4000)<br>IntegrationTime3DMid: 2Bytes (< 4000)<br>IntegrationTime3DHigh: 2Bytes (< 4000)<br>IntegrationTimeGrayscale: 2Bytes (< 50000)</td><td>Set all integration times at once. Unit are µs. To switch off an integration time set its value to 0.</td></tr>
<tr><td colspan="2">Example:
<table>
<tr><td>ID</td><td colspan="2">low integration time 3D image</td><td colspan="2">mid integration time 3D image</td><td colspan="2">high integration time 3D image</td><td colspan="2">integration time grayscale</td></tr>
<tr><td>0x01</td><td>0x00</td><td>0x64</td><td>0x03</td><td>0xE8</td><td>0x07</td><td>0xD0</td><td>0xC3</td><td>0x50</td></tr>
</table>
Low integration time 3D: 100us<br>Mid integration time 3D: 1000us<br>High integration time 3D: 2000us<br>Integration time grayscale: 50000us</td></tr>
<tr><td>GET_DISTANCE_AMPLITUDE</td><td>2<br>(0x02)</td><td>Stream (true/false): 1Byte
<table><tr><td>7Bit unused</td><td>1Bit Stream</td></tr></table></td><td>Get distance and amplitude as stream or single measurement</td></tr>
<tr><td>GET_DISTANCE</td><td>3<br>(0x03)</td><td>Stream (true/false): 1Byte
<table><tr><td>7Bit unused</td><td>1Bit Stream</td></tr></table></td><td>Get distance only as stream or single measurement</td></tr>
<tr><td>GET_GRAYSCALE</td><td>5<br>(0x05)</td><td>Stream (true/false): 1Byte
<table><tr><td>7Bit unused</td><td>1Bit Stream</td></tr></table></td><td>Get grayscale as stream or single measurement</td></tr>
<tr><td>GET_DCS</td><td>7<br>(0x07)</td><td>Stream (true/false): 1Byte
<table><tr><td>7Bit unused</td><td>1Bit Stream</td></tr></table></td><td>Get DCS data as stream or single measurement</td></tr>
<tr><td>STOP_STREAM</td><td>6<br>(0x06)</td><td>-</td><td>Stop streaming</td></tr>
<tr><td>SYSTEM_RESET</td><td>45<br>(0x2D)</td><td>-</td><td>Resets the CPU</td></tr>
<tr><td rowspan="2">SET_MIN_AMPLITUDE</td><td rowspan="2">21<br>(0x15)</td><td>MinAmplitude: unsigned 16Bit</td><td>Set the minimal Amplitude [LSB]; the limit where the pixel is set to “low Amplitude”</td></tr>
<tr><td colspan="2">Example:
<table>
<tr><td>ID</td><td colspan="2">minAmplitude</td></tr>
<tr><td>0x01</td><td>0x01</td><td>0x90</td></tr>
</table>
Minimum 3d amplitude = 400LSB</td></tr>
</table>

Table 8: Implemented commands

<table>
<tr><th>Command</th><th>ID</th><th>Parameters</th><th>Description</th></tr>
<tr><td>SET_FILTER</td><td>22<br>(0x16)</td><td>TemporalFilter factor: 2Bytes, unsigned 16Bit<br>TemporalFilter threshold: 2Bytes, unsigned 16Bit<br>MedianFilter enabled: 1Byte unsigned<br>AverageFilter enabled: 1Bytes unsigned<br>EdgeDetection threshold: 2Bytes, unsigned 16Bit<br>InterferenceDetection useLastValue: 1Byte unsigned<br>InterferenceDetection limit: 2Bytes, unsigned 16Bit</td><td>Set all filter settings at once.<br><br>Disable TemporalFilter:<br>Set factor to zero<br><br>Disable EdgeDetection:<br>Set threshold to zero<br><br>Disable interferenceDetection:<br>Set limit to zero</td></tr>
<tr><td rowspan="2">SET_MODULATION</td><td rowspan="2">23<br>(0x17)</td><td>Frequency: 1Byte<br>Channel: 1Byte<br>Reserved: 1Byte</td><td>Frequency:<br>0: 12 MHz<br>1: 24 MHz<br>2: 6 MHz<br>3: 3 MHz<br>4: 1.5 MHz<br>5: 0.75 MHz<br><br>Channel:<br>0 … 15</td></tr>
<tr><td colspan="2">Example:<br><table><tr><td>ID</td><td>frequency</td><td>channel</td><td>reserved</td></tr><tr><td>0x17</td><td>0x00</td><td>0x00</td><td>0x00</td></tr></table>Modulation frequency = 12MHz, channel = 0</td></tr>
<tr><td rowspan="2">SET_BINNING</td><td rowspan="2">24<br>(0x18)</td><td>Binning configuration: 1Byte</td><td>0: None<br>1: Vertical<br>2: Horizontal<br>3: Horizontal + Vertical</td></tr>
<tr><td colspan="2">Example:<br><table><tr><td>ID</td><td>binning config</td></tr><tr><td>0x18</td><td>0x00</td></tr></table>Mode: no binning</td></tr>
<tr><td rowspan="2">SET_HDR</td><td rowspan="2">25<br>(0x19)</td><td>HDR configuration: 1Byte<br><br>Response type: acknowledge</td><td>0: Off<br>1: Spatial HDR<br>2: Temporal HDR</td></tr>
<tr><td colspan="2">Example:<br><table><tr><td>ID</td><td>HDR config</td></tr><tr><td>0x19</td><td>0x00</td></tr></table>Mode: no HDR</td></tr>
<tr><td>READ_CHIP_INFOR-<br>MATION</td><td>36<br>(0x24)</td><td>-</td><td></td></tr>
<tr><td>READ_FIRMWARE_RELE<br>ASE</td><td>37<br>(0x25)</td><td>-</td><td></td></tr>
</table>

Table 9: Implemented commands

## 8.2. Responses

| Response (1 Byte) | Value | Payload | Description |
|---|---|---|---|
| ANSWER_ACK | 0 | - | The command has successfully been executed. |
| ANSWER_NACK | 255 | - | The command has not been received successfully |
| ANSWER_ERROR | 1 | Error number (2Bytes, unsigned 16Bit) | The command could not be executed. The error number contains the reason. |
| ANSWER_FIRMWARE_ RELEASE | 2 | Firmware Release, 4Bytes, unsigned 16Bit major, unsigned 16Bit minor | |
| ANSWER_CHIP_INFOR- MATION | 3 | Wafer ID, 2Bytes, unsigned 16Bit Chip ID, 2Bytes, unsigned 16Bit | |
| DATA_DISTANCE_AMPL ITUDE | | 4Bytes per pixel | refer to chapter 9.5 Measurement data |
| DATA_DISTANCE | | 2Bytes per pixel | refer to chapter 9.5 Measurement data |
| DATA_GRAYSCALE | | 2Bytes per pixel | refer to chapter 9.5 Measurement data |
| DATA_DCS | | 2Bytes per pixel x 4DCS | refer to chapter 9.5 Measurement data |

Table 10: Implemented Camera Answers

# 9. Measurement Data Connection (UDP)

## 9.1. Packetizing (transport layer)

The data of one measurement (for example distance) is divided (packetized) into as many UDP packets as needed to transport a complete measurement. Each packet contains the information to which measurement it belongs and where in the measurement it belongs to. The receiving application has to concatenate the payload in the single packets to reassemble the original image.

Example: This table shows a measurement containing a total of 30 Bytes, divided in 4 packets:

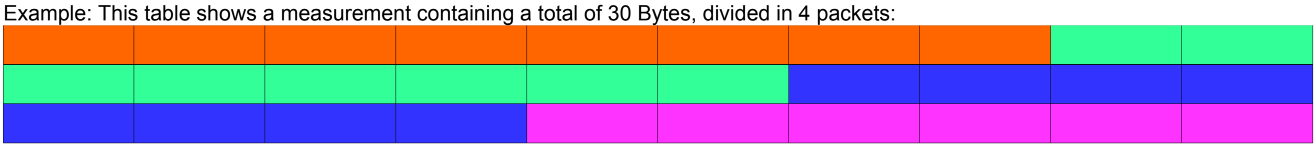


Figure 32: Example of packetizing measurement data

Packet 0: 8Bytes, offset 0
Packet 1: 8Bytes, offset 8
Packet 2: 8Bytes, offset 16
Packet 3: 6Bytes (remaining Bytes), offset 24

In reality the packages are much larger: 20 Bytes header and up to 1400 Bytes Payload.

Each UDP packet is divided into the fields shown in Figure 32. The single fields are explained in Table 11

| Element | Description |
|---|---|
| DataNumber | 16Bit unsigned, counter identifying the measurement. Will reset to zero after 65535 measurements |
| TotalSize | 32Bit unsigned, total size in bytes of the data for the whole measurement |
| PayloadSize | 16Bit unsigned, payload size (number of bytes) of the current packet |
| NumPacket | 32Bit unsigned, total number of packets belonging to this measurement |
| PacketNumber | 32Bit unsigned, number of the actual packet of the measurement |
| Offset | 32Bit unsigned, offset (number of bytes) where the payload of this packet must be copied into the receiving buffer |
| Payload | Payload of the packet as described above |

Table 11: UDP Packet fields

## 9.2. Payload (application layer)

After a successful measurement all image data are written into the payload. The payload contains a header with meta-data. This meta-data contains the actual settings of the sensor during image capture.

The payload is structured as shown in Figure 33.

| Header | Measurement data |
|---|---|

Figure 33: Payload structure

For transmission the payload is chopped into packets as described in chapter 9.1.

## 9.3. Payload Header

The Header is composed from the different fields as shown in figure 34. The single fields are explained in table 12.

| Version | Datatype | Width | Height | RoiX0 | RoiY0 | RoiX1 | RoiY1 | Int time low | Int time mid | Int time high | Tempe-rature | Offset | user data |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1Byte | 2Bytes | 2Bytes | 2Bytes | 2Bytes | 2Bytes | 2Bytes | 2Bytes | 2Bytes | 2Bytes | 2Bytes | 2Bytes | 2Bytes | 0 ... 1 kByte |

Figure 34: Payload Header

| Element | Bytes | Index | Description |
|---|---|---|---|
| Version | 1 | 0 | Version of the header structure, starting at 01. |
| Datatype | 2 | 1 | Type of measurement data, see table 13. |
| Width | 2 | 3 | Width of image in pixels |
| Height | 2 | 5 | Height of image in pixels |
| RoiX0 | 2 | 7 | Upper left corner in pixels of the region of interest |
| RoiY0 | 2 | 9 | Upper left corner in pixels of the region of interest |
| RoiX1 | 2 | 11 | lower right corner in pixels of the region of interest |
| RoiY1 | 2 | 13 | lower right corner in pixels of the region of interest |
| Int time 0 | 2 | 15 | Integration time 0 - low integration time 3D |
| Int time 1 | 2 | 17 | Integration time 1 - mid integration time 3D |
| Int time 2 | 2 | 19 | Integration time 3 - high integration time 3D |
| Temperature | 2 signed | 21 | Temperature in [0.01 °C] |
| DataOffset | 2 | 23 | Offset from package start where the measurement data starts (length of header plus user data) |
| UserData | 0 … 1024 | 25 | Copy of the data, that was transmitted together with the command. |

Table 12: Payload header fields

## 9.4. Data types and format of measurement data

| Value | Description | Data | | | |
|---|---|---|---|---|---|
| 0 | DATA_DISTANCE_AMPLITUDE | 4Bytes per pixel: | | | |
| | | 4Bit reserved | 12Bit Amplitude | 2Bit reserved | 14Bit Distance 0-16m (1mm/bit) |
| 1 | DATA_DISTANCE | 2Bytes per pixel: | | | |
| | | 2Bit Confidence | | 14Bit Distance (1mm/bit) | |
| 3 | DATA_GRAYSCALE | 2Bytes per pixel | | | |
| | | 5Bit unused | | 11Bit Grayscale | |
| 4 | DATA_DCS | 2Bytes per pixel x 4DCS | | | |
| | | 4Bit unused | | 12Bit DCS | |

Table 13: Type of actual measurement data

## 9.5. Measurement data

Each pixel is coded according to table 14. In cases where the distance or amplitude of a pixel can not be determined, error codes are inserted. Receiving application has to check for these error codes prior to further processing.

| Code | Situation | Used for data type |
|---|---|---|
| 0 ... 64000 | Valid value | Distance: distance in mm (12 / 24MHz) |
| 0 ... 2894 | Valid value | TOF Amplitude / Grayscale Amplitude: value in LSB |
| 64001 | Low Amplitude | Distance |
| 64002 | ADC-Overflow | Distance/Amplitude/DCS |
| 64003 | Saturation | Distance/Amplitude/Grayscale/DCS |
| 64004 | Bad pixel | All images |
| 64007 | Interference | Distance/Amplitude |
| 64008 | Edge filtered | Distance/Amplitude |

Table 14: Coding of pixels

# 10. Maintenance and disposal

## 10.1. 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!

## 10.2. 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.

# 11. Addendum

## 11.1. Related documents

Data sheet 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.)

## 11.2. 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

## 11.3. Licenses

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| Tool | Internet address | License holder |
|---|---|---|
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| ROS | www.ros.org | Open Source Robotics Foundation |

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