pco.edge 4.2
scientific CMOS camera

- High resolution: 2048 x 2048 pixel
- High quantum efficiency: > 70%
- High dynamic range: 37 500:1
- High speed: 100 fps
- Low noise: 0.8 electrons

Available features:
- Lightsheet scanning mode
- USB 3.0
- Camera Link
- Small form factor
features

Selectable rolling shutter operation modes of pco.edge cameras.

dual outside in  dual top down

dual inside out  single top down

rolling shutter readout modes – optimized for synchronization of microscopes and scanning applications

All pco.edge sCMOS cameras from the beginning feature a variety of precise synchronization modes, which are optimized for advanced microscopy imaging and scanning. The flexible frame and line triggers with very low latency in combination with the free selectable readout modes can easily be combined to cover every modern microscopy situation to name a few:

- lightsheet microscopy
- selective plane imaging microscopy (SPIM)
- structured illumination microscopy
- localizations microscopy (GSD, PALM, STORM, dSTORM)
- spinning disk confocal microscopy
- RESOLFT

For example, one mode is used in a lightsheet or SPIM application, the lower right rolling shutter operational mode “single top down” operation is convenient to properly synchronize the camera exposure with the scanner. On the other hand, if speed is required and a flash like exposure is applied the upper left mode “dual outside in” is used for localization microscopy techniques like GSD, PALM or STORM.
**free of drift**

The pco.edge sCMOS cameras feature temperature stabilized Peltier cooling, allowing for continuous operation free of drift phenomena in image sequences capture. This is achieved by the proper selection and sophisticated combination of electronics and FPGA algorithms.

As the measurement result shows while running at full speed of 100 frames/s over 4 hours measuring time the camera doesn’t show any significant drift (figure on the right side). This degree of stability enables long-term measuring series, which should be quantitatively evaluated and processed. For example, in PCR (Polymerase Chain Reaction) applications, when so-called melting curves must be measured, the fluorescence in multi-well plates with different samples is recorded over a longer time at different sample temperatures. Here all the images are used for processing, which is only possible if the offset is stable and the camera is free of drift.

**reaching emCCD domain**

In the past emCCD image sensors featuring on-chip amplification were developed to detect the lowest level of light. However, amplification, while reducing read out noise, comes at the expense of dynamic range. Both features are not possible simultaneously in emCCD sensors. In addition, the amplification process generates excess noise, which reduces the effective quantum efficiency ($\text{QE}_{\text{eff}}$) of the emCCD sensor by the factor of two (e.g. the 90 % QE of a back illuminated emCCD sensor has an $\text{QE}_{\text{eff}}$ of 45 %). The excess noise present in emCCDs makes the pco.sCMOS the sensor of choice at light conditions above 1 photon per pixel (at 70 % QE, assuming a cooled sensor with dark current = 0). Furthermore, available emCCD sensors are limited in resolution and frame rate.
**features**

**readout noise in sCMOS**

The EMVA 1288 standard explains that in principle for each pixel in an image sensor the noise behavior is determined by recording many images and calculating the time dependent variation or deviation of each pixel from its mean value. This is the determination of the root mean square (rms) value for each pixel. Since the widely used CCD image sensors don’t have a separate output stage for each pixel, the variation of the noise between each pixel is minimal. Therefore, instead of measuring many images, it is sufficient to measure two images, calculate the variance for each pixel and average these variances within the image to obtain an rms value for the image sensor. For CCD image sensors this simplification is a good approximation and has been now for years to describe the readout noise of image sensors in general.

However, CMOS image sensors, including scientific CMOS image sensors, feature a different behavior such that the simplified rms determination with the averaging across the whole image sensor is not sufficient to describe the noise behavior. The figure top right shows the result of time series of dark images, where for each pixel an rms value is calculated along the time axis and the results are shown in this histogram, showing the readout noise distribution for the total image sensor. Since two different pixel clocks are available in turn two curves are provided.

A valuable characterization of these rms value distributions is the so called median value, which is the point where 50% of all values are larger and smaller. For comparison the rms value measured by the simplified EMVA1288 approach is given. For a CCD image sensor these values would be identical, but for CMOS image sensors they start to diverge. For comparison of different cameras and image sensors both values can be used. For practical use it should be considered, that these values are calculated from a large series of recorded images.

The left figure shows the same fast scan curve of the pco.edge 4.2 only in a logarithmic y-axis (frequency) scaling, to emphasize that most of the pixels have an average readout noise in time that is smaller than 1 electron and there are few pixels (less than 1 % of the maximum), which have a readout noise of 3 – 6 electrons.

Noise distribution of the rms raw data values (noise filter off) of each pixel in the dark image of a pco.edge 4.2 at different readout speeds (slow scan / fast scan).

Noise distribution of the rms raw data values (noise filter off) of each pixel in the dark image of a pco.edge 4.2 at the fast readout speed. Graph is identical to figure on the top but in logarithmic y-axis scaling.
superior image quality
The pco.edge sCMOS camera features outstanding low read-out noise. Even at maximum speed of 100 frames/s at full resolution of 2048 x 2048 pixel the noise is 1.0 e⁻/med. Moreover the pco.edge provides an excellent homogeneous pixel response to light (PRNU, photo response non-uniformity) and an excellent homogeneous dark signal pixel behaviour (DSNU, dark signal non-uniformity), which is achieved by a sophisticated electronic circuit technology and firmware algorithms.

The lower figure shows a comparison of a scientific grade CCD and the new pco.sCMOS image sensor under similar weak illumination conditions. This demonstrates the superiority of sCMOS over CCD with regards to read out noise and dynamic, without any smear (the vertical lines in the CCD image).

flexibility and free of latency
User selectable choice of rolling shutter modes for exposure provides flexibility for a wide range of applications. The advantages of rolling shutter are high frame rates and low read out noise. Due to real-time transmission of the image data to the PC, there is no latency between recording and access or storage of the data.

33000:1 dynamic range
Due to the excellent low noise and the high fullwell capacity of the sCMOS image sensor an intra scene dynamic range of better than 33 000 : 1 is achieved (with 100 fps and fast scan read out mode). A unique architecture of dual column level amplifiers and dual 11 bit ADCs is designed to maximize dynamic range and to minimize read out noise simultaneously. Both ADC values are analyzed and merged into one high dynamic 16 bit value.
features

high resolution
A 4.2 Mpixel resolution in combination with a moderate chip size (18.8 mm diagonal, 6.5 μm pixel pitch) benefits microscopy applications with low magnification factor and large field of view, thereby reducing processing times and increasing throughput. The figure compares the potential of the new field of view of the pco.edge to the 1.3 Mpixel image resolution which is widely used in microscopy applications for scientific cameras.

high speed recording and data streaming
The new pco.edge offers in fast mode a frame rate of 100 frames/s (fps) at full resolution of 2048 x 2048 pixel as a full download stream to the PC. Therefore the recording time is just limited by either the amount of RAM in the PC or, in case of a RAID system, by the capacity and number of hard disks. As in many CMOS based cameras the frame rate increases significantly if smaller regions of interest (ROI) are used. The reduction of the image area works as well in favour of the frame rate of CCD sensors, but here unwanted regions still need to be read out at the expense of the total readout speed. The typical frame rate for a 1.3 Mpixel scientific CCD camera (6 e⁻ read out noise) is 10 fps. The new pco.edge camera provides at 1.3 Mpixel resolution (< 1.0 e⁻ readout noise) a frame rate of 200 fps in comparison.

The two images show in comparison the field of view with sCMOS resolution vs. a 1.3 Mpixel resolution, courtesy of Dr. Stefan Jakobs, Dept. of NanoBiophotonics, MPI for Biophysical Chemistry
technical data

<table>
<thead>
<tr>
<th>Image sensor</th>
<th>type of sensor</th>
<th>scientific CMOS (sCMOS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image sensor</td>
<td>CIS2020</td>
<td></td>
</tr>
<tr>
<td>Resolution (h x v)</td>
<td>2048 x 2048 active pixel</td>
<td></td>
</tr>
<tr>
<td>Pixel size (h x v)</td>
<td>6.5 μm x 6.5 μm</td>
<td></td>
</tr>
<tr>
<td>Sensor format / diagonal</td>
<td>13.3 mm x 13.3 mm / 18.8 mm</td>
<td></td>
</tr>
<tr>
<td>Shutter modes</td>
<td>rolling shutter (RS) with free selectable readout modes, lightsheet scanning mode¹</td>
<td></td>
</tr>
<tr>
<td>MTF</td>
<td>76.9 lp/mm (theoretical)</td>
<td></td>
</tr>
<tr>
<td>Fullwell capacity (typ.)</td>
<td>30 000 e⁻</td>
<td></td>
</tr>
<tr>
<td>Readout noise²</td>
<td>0.9 med / 1.4 rms e⁻ @ slow scan</td>
<td></td>
</tr>
<tr>
<td>1.0 med / 1.5 rms e⁻ @ fast scan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic range (typ.)</td>
<td>33 000 : 1 (90.4 dB) slow scan</td>
<td></td>
</tr>
<tr>
<td>Quantum efficiency</td>
<td>&gt; 70 % @ peak</td>
<td></td>
</tr>
<tr>
<td>Spectral range</td>
<td>370 nm .. 1100 nm</td>
<td></td>
</tr>
<tr>
<td>Dark current (typ.)</td>
<td>&lt; 0.5 e⁻/pixel/s @ 5 °C</td>
<td></td>
</tr>
<tr>
<td>DSNU</td>
<td>&lt; 1.0 e⁻ rms</td>
<td></td>
</tr>
<tr>
<td>PRNU</td>
<td>&lt; 0.5 %</td>
<td></td>
</tr>
<tr>
<td>Anti blooming factor</td>
<td>&gt; 10 000</td>
<td></td>
</tr>
</tbody>
</table>

Frame rate table³

<table>
<thead>
<tr>
<th>Type examples</th>
<th>Fast scan</th>
<th>Slow scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>2048 x 2048</td>
<td>100 fps</td>
<td>35 fps</td>
</tr>
<tr>
<td>2048 x 1024</td>
<td>200 fps</td>
<td>70 fps</td>
</tr>
<tr>
<td>2048 x 512</td>
<td>400 fps</td>
<td>140 fps</td>
</tr>
<tr>
<td>2048 x 256</td>
<td>800 fps</td>
<td>281 fps</td>
</tr>
<tr>
<td>2048 x 128</td>
<td>1600 fps</td>
<td>562 fps</td>
</tr>
<tr>
<td>1920 x 1080</td>
<td>189 fps</td>
<td>66 fps</td>
</tr>
<tr>
<td>1600 x 1200</td>
<td>170 fps</td>
<td>60 fps</td>
</tr>
<tr>
<td>1280 x 1024</td>
<td>200 fps</td>
<td>70 fps</td>
</tr>
<tr>
<td>640 x 480</td>
<td>426 fps</td>
<td>150 fps</td>
</tr>
<tr>
<td>320 x 240</td>
<td>853 fps</td>
<td>300 fps</td>
</tr>
</tbody>
</table>

Frame rate table extended readout mode⁴

<table>
<thead>
<tr>
<th>Type examples</th>
<th>Fast scan</th>
<th>Slow scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>2048 + 12 x 2048</td>
<td>100 fps</td>
<td>35 fps</td>
</tr>
<tr>
<td>2048 + 12 x 1024</td>
<td>200 fps</td>
<td>70 fps</td>
</tr>
</tbody>
</table>

¹ Selectable via SDK (software development kit).
² The readout noise values are given as median (med) and root mean square (rms) values, due to the different noise models, which can be used for evaluation. All values are raw data without any filtering.
³ Max. fps with centered ROI.
⁴ Extended readout mode with 12 columns of black reference pixel.
⁵ The high dynamic signal is simultaneously converted at high and low gain by two 11 bit A/D converters and the two 11 bit values are sophistically merged into one 16 bit value.

Camera

<table>
<thead>
<tr>
<th>Camera</th>
<th>Frame rate</th>
<th>100 fps @ 2048 x 2048 pixel, fast scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure / shutter time</td>
<td>100 μs .. 10 s</td>
<td></td>
</tr>
<tr>
<td>Dynamic range A/D⁵</td>
<td>0.46 e⁻/count</td>
<td></td>
</tr>
<tr>
<td>Pixel scan rate</td>
<td>272.3 MHz fast scan</td>
<td></td>
</tr>
<tr>
<td>95.3 MHz slow scan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pixel data rate</td>
<td>544.6 Mpixel/s</td>
<td></td>
</tr>
<tr>
<td>190.7 Mpixel/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Binning horizontal</td>
<td>x1, x2, x4</td>
<td></td>
</tr>
<tr>
<td>Binning vertical</td>
<td>x1, x2, x4</td>
<td></td>
</tr>
<tr>
<td>Region of interest (ROI)</td>
<td>horizontal: steps of 1 pixel</td>
<td></td>
</tr>
<tr>
<td>Vertical: steps of 1 pixel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non linearity</td>
<td>&lt; 1 %</td>
<td></td>
</tr>
<tr>
<td>Cooling method</td>
<td>+ 5 °C stabilized</td>
<td></td>
</tr>
<tr>
<td>Selectable: peltier with forced air (fan) or water cooling (both up to 27 °C ambient)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trigger input signals</td>
<td>Frame trigger, sequence trigger, programmable input (SMA connectors)</td>
<td></td>
</tr>
<tr>
<td>Trigger output signals</td>
<td>Exposure, busy, line, programmable output (SMA connectors)</td>
<td></td>
</tr>
<tr>
<td>Data interface</td>
<td>Camera Link Full (10 taps, 85 MHz)</td>
<td></td>
</tr>
<tr>
<td>Time stamp</td>
<td>In image (1 μs resolution)</td>
<td></td>
</tr>
</tbody>
</table>

General

<table>
<thead>
<tr>
<th>General</th>
<th>Power supply</th>
<th>12 .. 24 VDC (+/- 10 %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power consumption</td>
<td>20 W max. (typ. 10 W @ 20 °C)</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>700 g</td>
<td></td>
</tr>
<tr>
<td>Operating temperature</td>
<td>+ 10 °C .. + 40 °C</td>
<td></td>
</tr>
<tr>
<td>Operating humidity range</td>
<td>10 % .. 80 % (non-condensing)</td>
<td></td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>- 10 °C .. + 60 °C</td>
<td></td>
</tr>
<tr>
<td>Optical interface</td>
<td>F-mount &amp; C-mount</td>
<td></td>
</tr>
<tr>
<td>CE / FCC certified</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
The readout noise values are given as median (med) and root mean square (rms) values, due to the different noise models, which can be used for evaluation. All values are raw data without any filtering.

2 Max. fps with centered ROI.

3 The high dynamic signal is simultaneously converted at high and low gain by two 11 bit A/D converters and the two 11 bit values are sophistically merged into one 16 bit value.
technical data

quantum efficiency

monochrome

dimensions

F-mount and C-mount lens changeable adapter.

All dimensions are given in millimeter.
technical data

software
For camera control, image acquisition and archiving of images in various file formats PCO provides the software application Camware (Windows 7, 8 and later).

A camera SDK (software development kit) including a 32 / 64 bit dynamic link library for user customization and integration on PC platforms is available for free.

For camera interface drivers and a list of supported third party software please visit www.pco.de.

options
custom made versions
(e.g. water cooling, deep cooled,...)

third party integrations

software drivers

Water cooling unit Aquamatic II for use with pco.edge cameras.
sCMOS solutions

**pco.edge with CameraLinkHS**

CameraLinkHS is the new high-speed interface standard for ultra-high performance cameras. As an active member of the AIA CameraLinkHS subcommittee we are one of the first to implement the 10G (10.3125Gbps) data throughput solution.

Main advantages of the CameraLinkHS interface:

- MM fiber optic cable (up to 450 meters)
- SM fiber optic cable (up to several kilometers)
- Thin, lightweight & flexible fiber optic cables
- Max. data bandwidth of 1.2 GByte/s
- No EMI issues

Available in our **sCMOS pco.edge** family!

**pco.edge board level**

PCO offers board level pco.edge series camera modules for OEM customization. The modules can be equipped with different sCMOS sensors, different interfaces and various features such as special read out modes. PCO also offers custom designed circuit boards with various form factors and sizes to meet special customer needs. Please contact us directly to discuss additional details.
applications

life science

A widefield (right) and a GSDIM super-resolution (left) microscopy image of tubulin fibers obtained with a pco.edge, courtesy of Leica Microsystems, Germany

A single image of fluorescence labeled protein networks in water drops in an oil phase, which moved fast. One pixel corresponds to 0.1625 μm in reality, courtesy of Prof. Dr. Sarah Köster, Institute for X-Ray Physics, Göttingen, Germany

Zebrashh with two fluorescent labels, collected with a VasiScope Confocal based on the Yokogawa CSU-W1 wide head and a pco.edge camera, courtesy of VisiRon Systems GmbH, Germany

life science

Neuronal network marked with a fluorophore (false color rendering) and recorded with a pco.edge.

Extract of a fluorescent slide which was scanned by a pco.edge camera in a Pannoramic 250 Flash scanner for digital pathology, courtesy of 3DHistech, Hungary

An image of a sequence, which was recorded with a pco.edge at 400 frame/s. The maximum signal was about 100 photons, courtesy of Prof. Engstler, University of Würzburg, Germany

application areas

- Widefield microscopy
- Fluorescent microscopy
- Digital pathology
- PALM
- STORM
- GSDIM
- dSTORM
- Superresolution microscopy
- Lightsheet microscopy
- Selective plane imaging microscopy (SPIM)
- Calcium imaging
- FRET
- FRAP
- 3D structured illumination microscopy
- High speed bright field ratio imaging
- High throughput screening
- High content screening
- Biochip reading
- TIRF
- TIRF microscopy / waveguides
- Spinning disk confocal microscopy
- Live cell microscopy
- 3D metrology
- TV / broadcasting
- Ophthalmology
- Electro physiology
- Lucky astronomy
- Photovoltaic inspection

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