A year ago, the new scientific CMOS image sensor technology was presented to the public. Twelve months later, the first camera systems incorporating this technology are appearing on the market. For the case of the pco.edge, we want to test whether the promises have been met and, at the same time, identify the applications that could make use of the sCMOS sensor’s qualities.

GERHARD HOLST

Because the technical parameters of an image sensor and the camera that uses it can vary widely, we should first take a look at the datasheet for the pco.edge:
- resolution 2560×2160 pixels,
- readout noise <1.4 electrons at 30 frames per second,
- usable full well capacity 30000 electrons,
- dynamic range >22000:1,
- maximum frame rate 100 frames/s (full resolution), and
- quantum efficiency maximum 57 percent (front illuminated).

Compared to the values described earlier [1], the resolution has remained the same. However, the achievable readout noise is lower than previously expected, as at frame rates of 30 frames/s the camera achieves noise values of <1.4 electrons which, with the usable full well capacity, corresponds to intrascene dynamics [2] of 22000:1 (better than the 16000:1 announced last year). Therefore, the use of 16 bit A/D converters appears to be fully justified when we take into account their characteristic error rate of typically 0.5 bits.

The maximum frame rate is still specified at 100 frames/s, albeit with one minor caveat. The theoretical maximum data rate possible with the fastest camera data interface currently available (Camera Link) is 850 MB/s, although practically, and even then only with a sophisticated read system and an excellent frame grabber, 800 MB/s is more realistic. Given that the sCMOS camera can deliver 1.14 GB/s, the actual data transfer rate is ultimately limited by the currently available interface standards. The net result is that the full frame rate can only be utilized together with data compression or a reduced dynamic range. The second limitation, at least compared to the information made available last year, lies in the slightly reduced quantum efficiency. The actual specification includes losses from cover glasses and the slightly lower values attained for the series production sCMOS image sensors, although the minor drop from 60 to 57 percent is very likely tolerable for most applications. In spite of this, the sensitivity in the NIR is still significantly higher than conventional CCD or CMOS image sensors.

CONTACT

PCO AG
93309 Kelheim, Germany
Tel. +49 (0)9441 2005-0
Fax +49 (0)9441 2005-20
www.pco.de
In order to influence the flagellates as little as possible, appropriate tagging proteins were used to mark the cell membrane with a fluorescent dye, and the trypanosomes were then observed in a liquid environment on the slide of an inverse digital iNIR microscope (Figure 2) coupled to a sCMOS camera. For the very first time, image sequences of the characteristic movement of the fluorescent trypanosomes to be captured with sufficient time resolution. Sequences with 1120 x 1080 pixels were captured at 200 frames/s and with 1120 x 502 pixels at 400 frames/s. A sequence of four (cropped) images can be seen in Figure 3. Given the short time intervals between images, the significant change in posture of the two trypanosomes is indicative of how quickly these flagellates move. The light signals comprise around 100 photons at the brightest locations, which is of course a very weak signal. These sequences of images are currently being studied and processed, particularly in terms of the three-dimensional characteristics of the movement and further investigations will follow.

Macro – NIR sensitivity, resolution and noise

For several years now, the electro-luminescence (EL) of solar cells has been used as a significant parameter in research.
and quality assurance. Scientific studies have shown that the areas of solar cells that do not exhibit EL do not make a contribution to the generated photoelectric current. Solar cell research is currently engaged in particular on the proper interpretation and significance of EL measurements.

To produce the EL, a safe nominal current is applied in the flow direction that mimics the expected photovoltaic current through individual solar cells or entire modules. Light with an intensity maximum around 1150 nm in the near infrared is generated in the cells - notably outside the sensitivity range of the camera sensor. Nevertheless, the component of the EL intensity with a wavelength below roughly 1050 nm is sufficient to generate a usable signal. Until recently, specially optimized CCD cameras have been used for this task, but they either needed to utilize pixel binning to produce a sufficiently visible image or required longer exposure times in the range of 30 to 60 seconds or more.

In addition to the high resolution, the sCMOS image sensor also has a better quantum efficiency than front-illuminated CCDs. And unlike deep depletion CCDs, all of which are illuminated from the rear through the substrate, there is also no etaloning. Figure 4 shows the EL for a solar cell module, captured using a special IR objective from Carl Zeiss. The exposure time was 700 ms, meaning that the type of EL image capture needed for quality assurance can be taken easily during manufacture. In Figure 4, a defect is marked with an arrow. Current research still needs to provide answers to improve understanding and identify the significance of the other darker areas.

Aero - frame rate, dynamic range and resolution

The DLR Institute for Robotics and Mechatronics in Berlin has been developing aerial reconnaissance systems for some time. Through the use of additional sensors, the absolute position of the aircraft is very accurately known and it becomes possible to ensure that adjacent images of a target area always have at least 90 percent overlap. Sophisticated algorithms can then be applied to these images to obtain a height profile of the target area.

At present, high-resolution CCD cameras such as the pco.4000 (4008 x 2672 pixels with color sensor) are being used, and that capture images with sufficient speed (3 frames/s). With this camera a single pixel corresponds to 2 cm on the ground (Figure 5), achieved at an altitude of around 150 m. The resolution calculated for the height profile is around 3 cm. The disadvantages of the pco.4000 include its size and, above all, its tendency to smears images (the stripe-like artifacts left behind in images due to very bright spots of light in the imaged scene).

sCMOS cameras with a color sensor are now to be integrated into these aerial photographic systems. Although they only have half the resolution, they produce no smear effects and also have a considerably higher frame rate. In addition they benefit from a better dynamic range, a more compact format (Figure 1) and they weigh less. The aim is to improve the resolution of the height profiles from 3 to 1 cm for this research work. By
flying over a road construction site before, during and after construction, this kind of system could then be used to determine exactly how much excavation was actually carried out. Other applications include creating height models of major population centers, so that detailed emergency response plans can be formulated, or determining the exact size and extent of cities in countries where building activity has not been continuously recorded.

**Summary**

The original announcement of the sCMOS camera systems and the significant interest in the performance specifications prompted a deluge of potential applications in fields ranging from micro to macro. From microscopy through to aerial photography, there is certainly no lack of interest in the capabilities of the sCMOS image sensor technology. Potential applications can easily be envisaged that range from super-resolution optical microscopy, over DNA analysis and even on to 3D film capture and 2D stereo image acquisition. The term »scientific CMOS« also appears to have drawn so much attention that it is increasingly being used to describe lesser performant CMOS image sensors in order to emphasize their qualities.

**LITERATURE / REFERENCES**

2. The intrascene dynamic range is defined as the ratio of the maximum fill level to the smallest distinguishable signal level (comparable to the noise). This dynamic is the customary dynamic range generally specified for digital camera systems.
3. Department of Zoology (Cell and Development Biology) at the Biological Center of the University of Würzburg, in his article in Labor & More 3 (2010).

**AUTHOR**

GERHARD HOLST studied information technology at the RWTH Aachen. After seven years in the microsensor research group at the MPI for Marine Microbiology in Bremen, he moved to PCB. He is head of the science and research department at PCB.