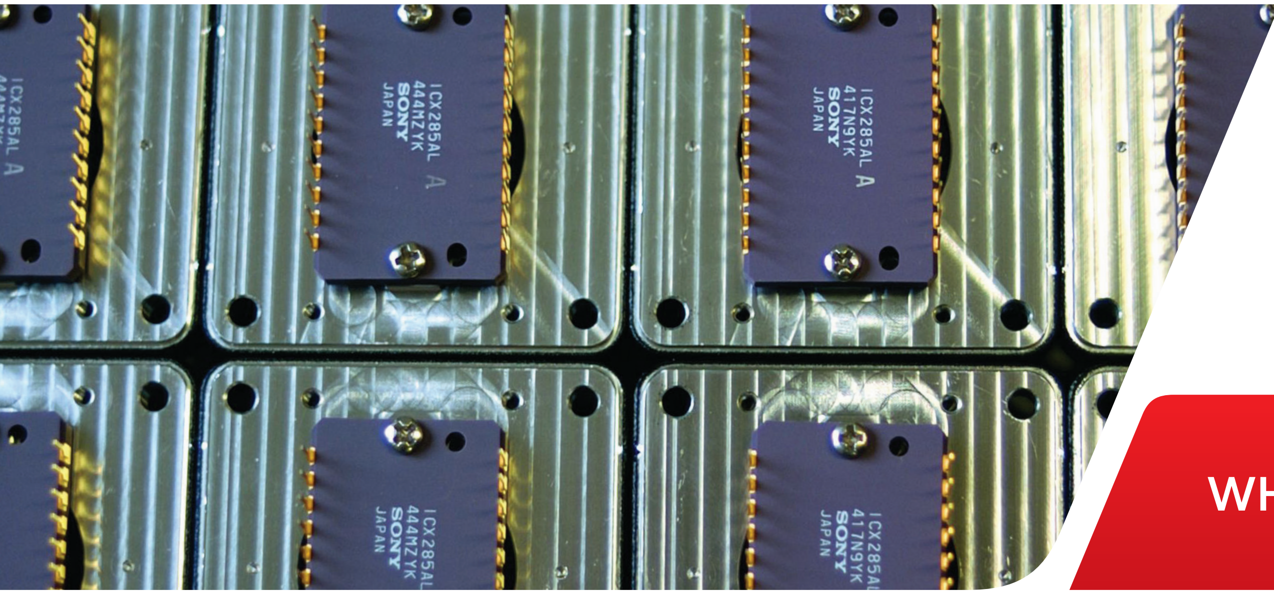

WHITE PAPER

CCD or CMOS - Key differences between both sensor technologies

When Sony announced they were discontinuing their CCD sensors back in 2015, the news generated many questions. Users valued the image quality for specific applications with low light conditions, long exposure times or scientific imaging. However, most applications are based on CMOS sensors nowadays, which has seen many technological advancements in recent years, such as:

// **Pixel performance:**
Improved microlenses and backside illumination have boosted light sensitivity, dynamic range, and low-light performance.

// **Resolution and speed:**
Sensor size has increased while pixel size shrinks, enabling higher resolutions and faster frame rates.

// **Integration and intelligence:**
Sensors are integrating more functionality like sensor binning, ultra short exposure times, and HDR.

With the final discontinuation notice released by Sony on 01.03.2024, many users are now faced with the challenge of migrating from CCD to CMOS based cameras. In the following paper, commonalities and differences of CCD and CMOS sensors will be analyzed in order to provide guidance for affected customers.

Image 1: Compact Alvium camera with CMOS sensor

CCD and CMOS: Sensor technology for the visible spectral range

CCD and CMOS sensors belong to quantum detectors. Both technologies are based on silicon, the semiconductor material, and are sensitive in the same spectral range from approximately 300 to 1000 nm.

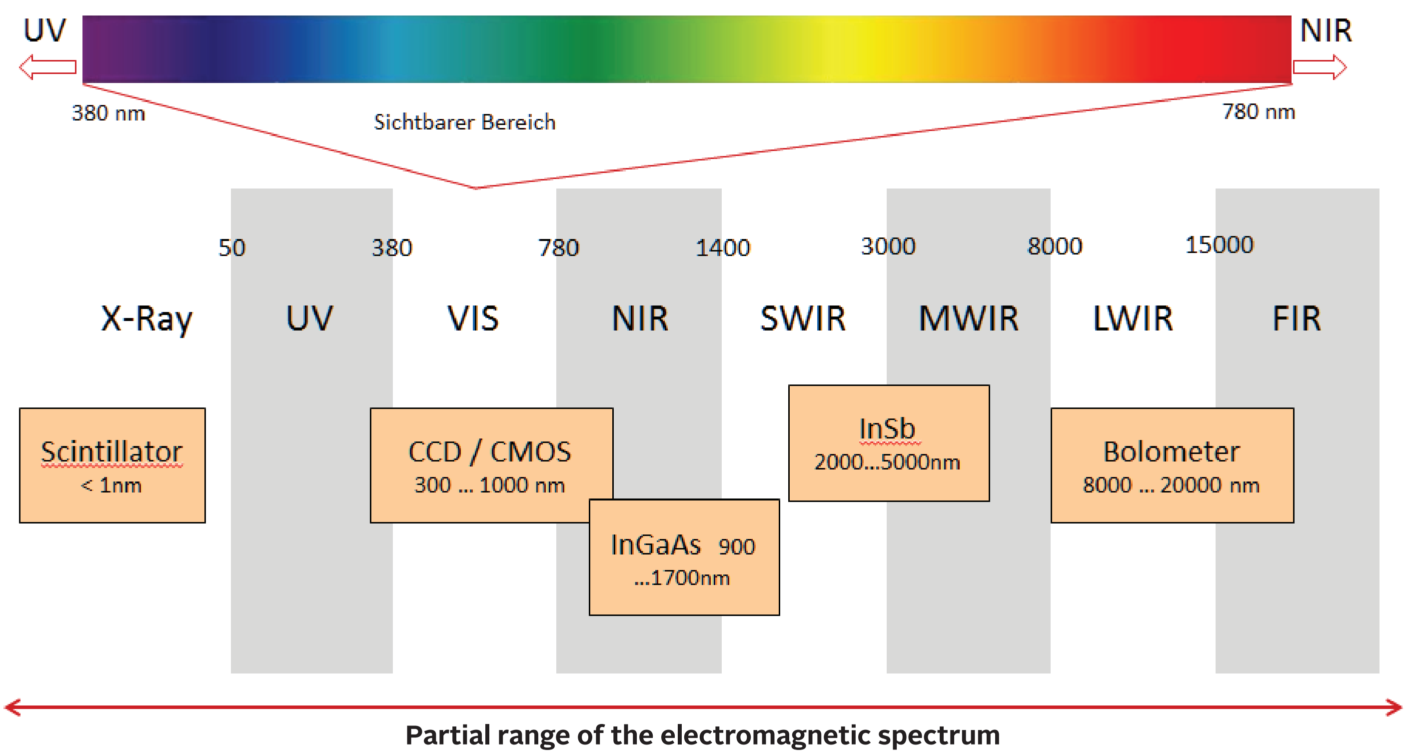

Image 2: optical sensors and the electromagnetic spectrum

But in what ways do the two technologies differ? The principal difference lies in the semiconductor element where the charge is converted into voltage. In a CCD sensor, a vertical and horizontal charge transport first takes place. The serial charge/voltage conversion of all pixels takes place outside the sensor in the camera's electronics. All pixel charges are converted via an output outside the sensor to an analog voltage.

In contrast, the charge/voltage conversion in CMOS sensors occurs in every pixel on the sensor. Corresponding to the activated line, the signal is amplified via the readout circuit, noise-minimized and digitized, and finally transmitted in parallel via a configurable number of LVDS (Low Voltage Differential Signaling) wires.

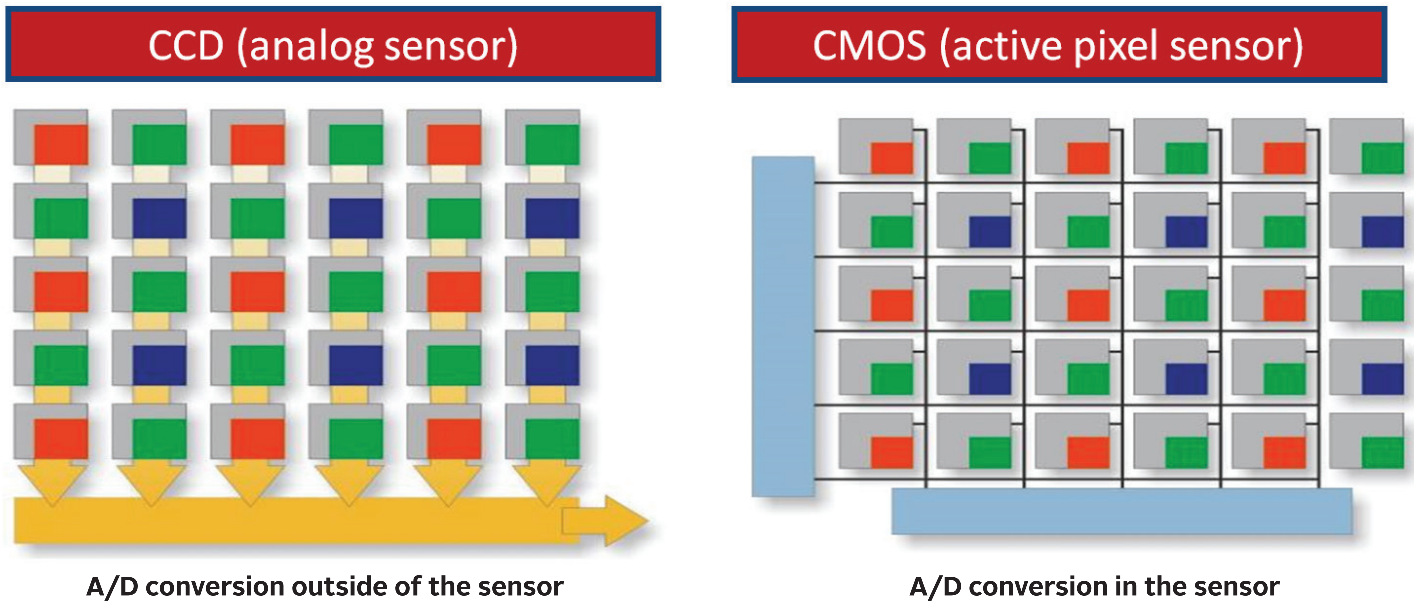

Image 3: principle of the interline transfer CCD as well as of the CMOS sensor

CCD sensor advantages and disadvantages

In a CCD sensor, all pixel charges are converted via an output to an analog voltage, amplified and digitized. In doing so, a high quality image with high pixel homogeneity, very uniform signal with low fixed pattern noise and usually low dark current, is achieved.

Furthermore, CCDs achieve high sensitivity as well as good signal quality in low light conditions due to the higher fill factor (relationship of the photosensitive area to the entire pixel area).

Another advantage lies in the perfect Global Shutter, i.e., the concurrent illumination of all pixels. For this reason, CCDs are well suited for use in machine vision applications, especially those requiring very short exposure times.

One disadvantage to CCD sensors lies in the limited readout speed of the serial data stream. Therefore, modern CCDs with higher resolutions are commonly manufactured in multi-tap technologies (division of the sensor into several image areas) in order to achieve the n-fold readout speed compared to single-tap sensors.

However, this has the disadvantage that a signal adjustment (gain offset correction) of the tap becomes necessary, as even the slightest deviations lead to visible differences at the limit tap edges.

Another disadvantage to CCD sensors is that charges which exceed the full well capacity of the pixel cell impinge into neighboring pixels. This becomes visible in typical blooming effects. The only remedy is a reduction of the occurring amount of light. Moreover, during the readout of a serial charge transport in the vertical shift register, impinging photons can produce additional charge carriers – resulting in so-called smearing. Smearing can be prevented by using a mechanical shutter in front of the sensor or by using flash lighting.

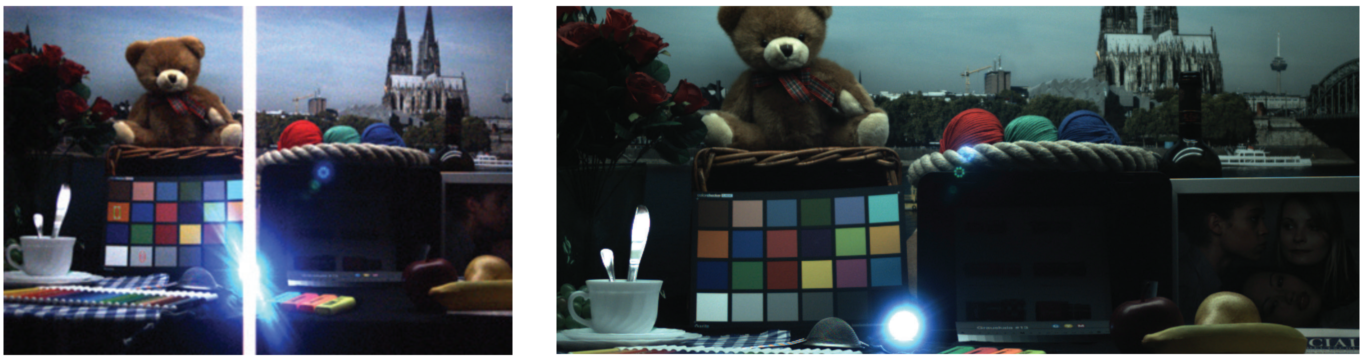

Image 4: on the left, CCD blooming and smearing artifacts; on the right, CMOS sensor without these artifacts

Advantages and disadvantages of CMOS sensors

In a CMOS sensor, the charge/voltage conversion takes place in each pixel and the image information is converted to digital information on the CMOS sensor chip. This type of function requires an elevated design complexity. More complex CMOS designs with Global Shutter and CDS (Correlated Double Sampling) to reduce fixed pattern noise are based on pixel cells with 5 to 8 transistors and thus reduce the light-sensitive area per pixel.

Every column/pixel possesses an amplifier that works independently of the others. Due to deviations caused by the technology used, disparities arise in the uniformity between the pixels of the individual columns, which again leads to increased fixed pattern noise.

For applications with moving objects, a Global Shutter sensor function is necessary. This requires the CMOS sensor to contain a storage area in the pixel that is protected from light as much as possible. In practice, this is not successful in older CMOS designs – the area is more or less light sensitive and demonstrates a parasitic light sensitivity during pixel data readout. Particularly at short exposure times in the microsecond range, it becomes clearly visible as a vertical grayscale value.

However, parallel readout of the image information from a CMOS sensor offers the advantage of higher frame rates at comparable resolutions, according to the number of LVDS wires. Moreover, a faster and more flexible readout can be achieved when individual pixels are addressed by one or several regions of interest.

Since charges in the CMOS sensor need not be shifted vertically and horizontally, but rather are converted to voltage directly on the pixel, bloom-ing and smearing artifacts do not arise. Thus, CMOS sensors can deal with overexposure. Using High Dynamic Range mode within an image, visualization of high-contrast and extremely bright objects as well as darker image areas is possible.

An additional advantage of CMOS sensor technology lies in the integration of the control circuit (clock generation, amplifier, A/D converter) on the sensor chip. Therefore, camera construction is more cost-effective than with CCD and cameras have a lower power consumption.

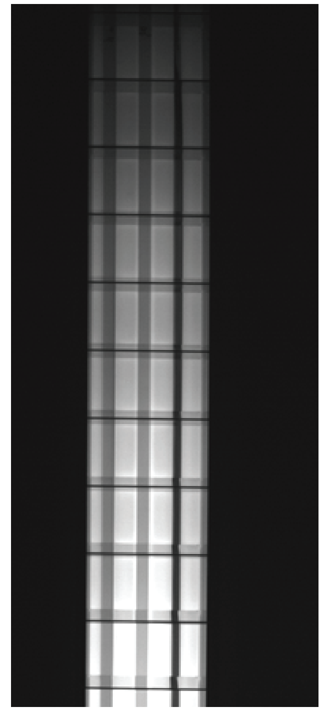

Image 5: vertical grayscale value resulting from parasitic light sensitivity during readout

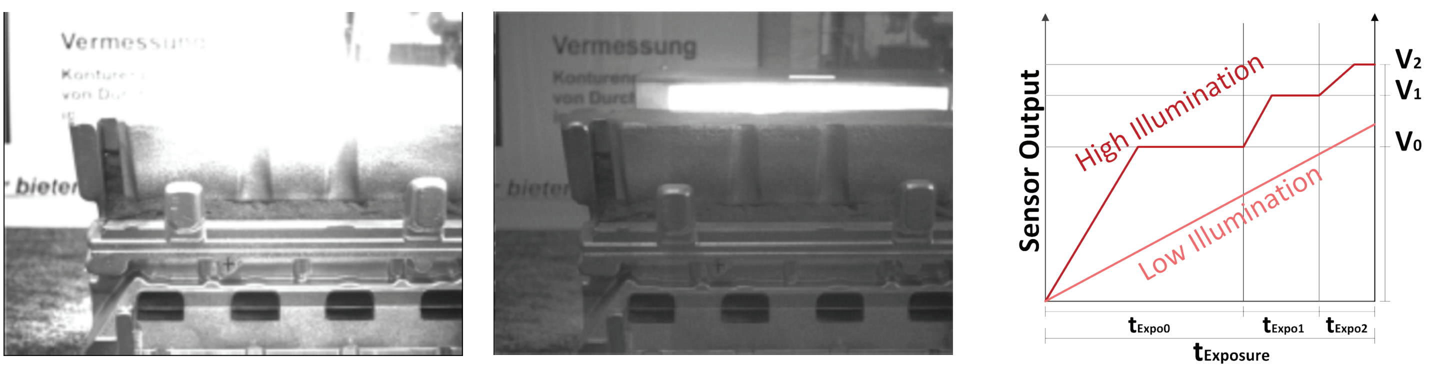

Image 6: on the right, activated HDR mode in the Allied Vision Mako G-030 with a CMV300 CMOS sensor

CMOS: Future Proof sensor technology

In recent years, CMOS technology has demonstrated clear advances in image quality, resolution and framerates and is widely considered as the dominant sensor technology in both machine and embedded vision. Manufacturers such as Sony or On Semi were able to significantly improve their CMOS designs.

Modern CMOS sensors come with both Global and Rolling Shutter with frame rates up to 190 frames at 4k resolution. By reducing the dark and fixed pattern noise as well as raising the quantum efficiency, these sensors deliver good image quality even in low light conditions. The memory's parasitic light sensitivity during readout has been reduced essentially.

The result is an improved Global Shutter efficiency with values in the range of 10000:1 or better. As such, modern CMOS sensors are well-suited for applications with moving objects. Allied vision further improves the image quality of CMOS sensors by adding Fixed Pattern Noise Correction, Defect Pixel Correction as well as Active Sensor Alignment during the automated manufac-turing process.

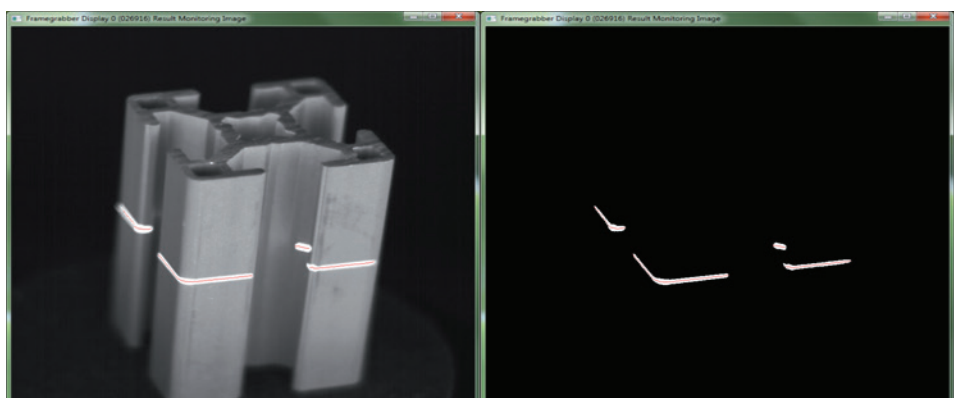

Image 7: laser triangulation for 3D measurements of structural beam

Applications in which CCD sensors continue to be used

Due to their very homogenous image quality with low fixed pattern noise, CCD sensors have advantages for medical and scientific applications, particularly for fluorescence microscopy and high-resolution microscopy. For application fields requiring very high resolution, such as aerial mapping, CCD sensors are also well suited. Furthermore, CCDs offer advantages for applications with long exposure times, such as applications in astronomy, due to minimal dark current.

Conclusion

Due to the continuous development of CMOS sensor technology in recent years, CMOS sensors are almost always preferable to CCD sensors in terms of image quality, frame rate, resolution, and cost-performance ratio. While some specialized applications might still benefit from CCD's low-light noise performance, the now necessary transition towards CMOS based cameras is the logical next step for many users.

Additionally, Allied Vision is pleased to offer affected customers and partners access to appropriate successor products built on our Alvium platform as well as on the EXO series of our sister company SVS-Vistek (like Allied Vision part of TKH Vision).

For further information or to explore options such as Last-Time-Buy or potential migration to our future-proof platforms, we encourage you to reach out to your dedicated sales representative.

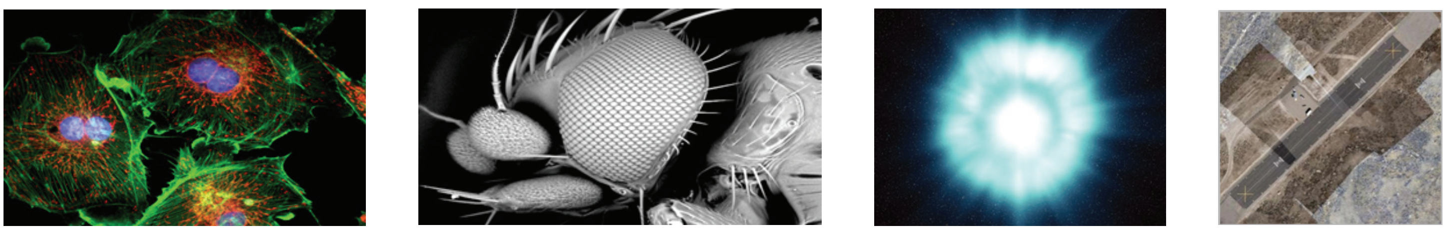

Image 8: Applications using CCD cameras (fluorescence microscopy, high-resolution microscopy, astronomy, aerial mapping)

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