WHITE PAPER

CCD and CMOS sensor technology

Technical white paper

AXIS COMMUNICATIONS

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1. Introduction to image sensors

When an image is being captured by a network camera, light passes through the lens and falls on the image sensor. The image sensor consists of picture elements, also called pixels, that register the amount of light that falls on them. They convert the received amount of light into a corresponding number of electrons. The stronger the light, the more electrons are generated. The electrons are converted into voltage and then transformed into numbers by means of an A/D-converter. The signal constituted by the numbers is processed by electronic circuits inside the camera.

Presently, there are two main technologies that can be used for the image sensor in a camera, i.e. CCD (Charge-coupled Device) and CMOS (Complementary Metal-oxide Semiconductor). Their design and different strengths and weaknesses will be explained in the following sections. Figure 1 shows CCD and CMOS image sensors.

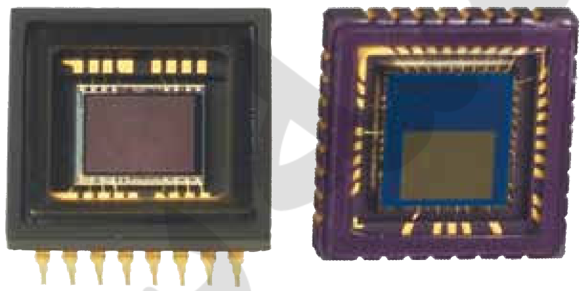

Figure 1. Image sensors: CCD (left) and CMOS (right)

Color filtering

Image sensors register the amount of light from bright to dark with no color information. Since CMOS and CCD image sensors are 'color blind', a filter in front of the sensor allows the sensor to assign color tones to each pixel. Two common color registration methods are RGB (Red, Green, and Blue) and CMYG (Cyan, Magenta, Yellow, and Green). Red, green, and blue are the primary colors that, mixed in different combinations, can produce most of the colors visible to the human eye.

The Bayer array, which has alternating rows of red-green and green-blue filters, is the most common RGB color filter, see Figure 2 (left). Since the human eye is more sensitive to green than to the other two colors, the Bayer array has twice as many green color filters. This also means that with the Bayer array, the human eye can detect more detail than if the three colors were used in equal measures in the filter.

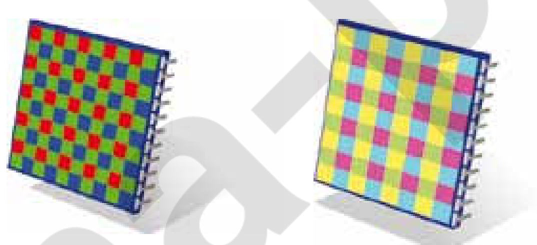

Figure 2. Bayer array color filter (left) and CMYG color filter array (right)

Another way to filter or register color is to use the complementary colors—cyan, magenta, and yellow. Complementary color filters on sensors are often combined with green filters to form a CMYG color array, see Figure 2 (right). The CMYG system generally offers higher pixel signals due to its broader spectral band pass. However, the signals must then be converted to RGB since this is used in the final image, and the conversion implies more processing and added noise. The result is that the initial gain in signal-to-noise is reduced, and the CMYG system is often not as good at presenting colors accurately.

The CMYG color array is often used in interlaced CCD image sensors, whereas the RGB system primarily is used in progressive scan image sensors. For more information about interlaced CCD image sensors and progressive scan image sensors, see the links in Chapter 7.

2. CCD technology

In a CCD sensor, the light (charge) that falls on the pixels of the sensor is transferred from the chip through one output node, or only a few output nodes. The charges are converted to voltage levels, buffered, and sent out as an analog signal. This signal is then amplified and converted to numbers using an A/D-converter outside the sensor, see Figure 3.

The CCD technology was developed specifically to be used in cameras, and CCD sensors have been used for more than 30 years. Traditionally, CCD sensors have had some advantages compared to CMOS sensors, such as better light sensitivity and less noise. In recent years, however, these differences have disappeared.

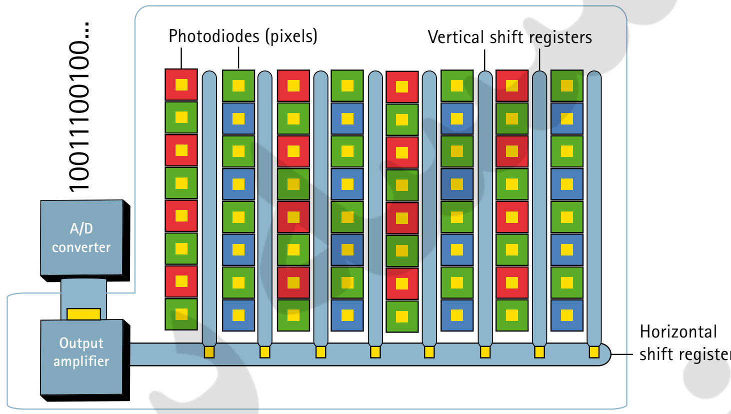

Figure 3. CCD operation (video-type CCD)

The disadvantages of CCD sensors are that they are analog components that require more electronic circuitry outside the sensor, they are more expensive to produce, and can consume up to 100 times more power than CMOS sensors. The increased power consumption can lead to heat issues in the camera, which not only impacts image quality negatively, but also increases the cost and environmental impact of the product.

CCD sensors also require a higher data rate, since everything has to go through just one output amplifier, or a few output amplifiers. Compare Figure 4 showing a CCD PCB (Printed Circuit Board) with Figure 5 showing a CMOS PCB.

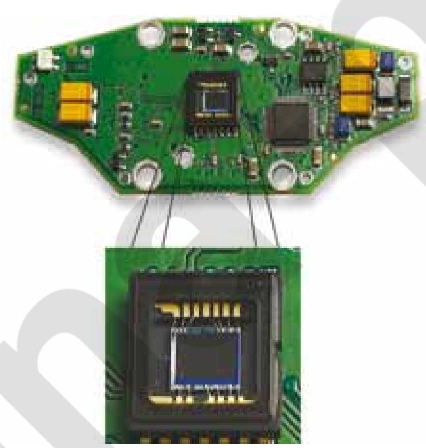

Figure 4. CCD sensor mounted on a PCB

3. CMOS technology

Early on, ordinary CMOS chips were used for imaging purposes, but the image quality was poor due to their inferior light sensitivity. Modern CMOS sensors use a more specialized technology and the quality and light sensitivity of the sensors have rapidly increased in recent years.

CMOS chips have several advantages. Unlike the CCD sensor, the CMOS chip incorporates amplifiers and A/D-converters, which lowers the cost for cameras since it contains all the logics needed to produce an image. Every CMOS pixel contains conversion electronics. Compared to CCD sensors, CMOS sensors have better integration possibilities and more functions. However, this addition of circuitry inside the chip can lead to a risk of more structured noise, such as stripes and other patterns. CMOS sensors also have a faster readout, lower power consumption, higher noise immunity, and a smaller system size.

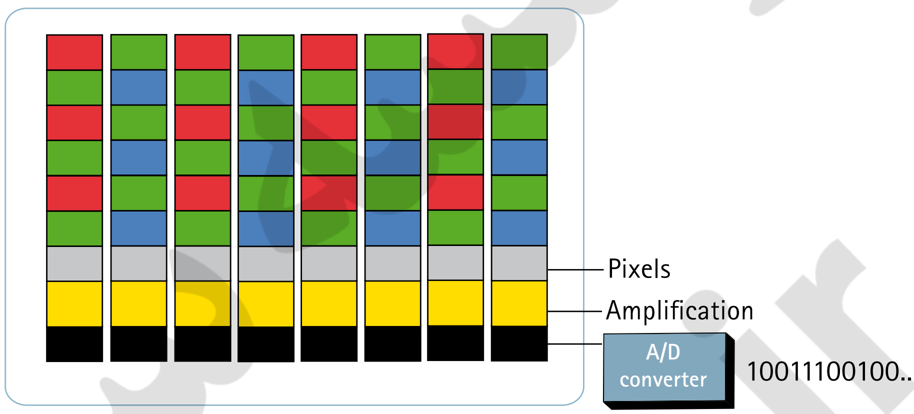

Figure 5. CMOS sensor

Calibrating a CMOS sensor in production, if needed, can be more difficult than calibrating a CCD sensor. But technology development has made CMOS sensors easier to calibrate, and some are nowadays even self-calibrating.

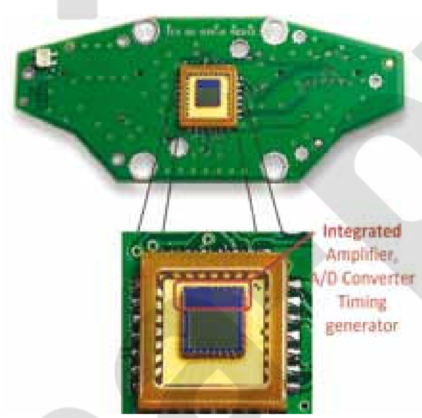

Figure 6. CMOS sensor mounted on a PCB

It is possible to read individual pixels from a CMOS sensor, which allows 'windowing', which implies that parts of the sensor area can be read out, instead of the entire sensor area at once. This way a higher frame rate can be delivered from a limited part of the sensor, and digital PTZ (pan/tilt/zoom) functions can be used. It is also possible to achieve multi-view streaming, which allows several cropped view areas to be streamed simultaneously from the sensor, simulating several 'virtual cameras'.

4. HDTV and megapixel sensors

Megapixel and HDTV technology enables network cameras to provide higher resolution video images than analog CCTV cameras, i.e. they improve the possibility to see details and to identify people and objects — a key consideration in video surveillance applications. A megapixel or HDTV network camera offers at least twice as high a resolution as a conventional, analog CCTV camera. Megapixel sensors are key components in HDTV, megapixel and multi-megapixel cameras and can be used to provide extremely detailed images and multi-view streaming.

Megapixel CMOS sensors are more widely available and generally less expensive than megapixel CCD sensors – even though there are plenty examples of very costly CMOS sensors.

It is difficult to make a fast megapixel CCD sensor, which of course is a disadvantage, and which makes it difficult to build a multi-megapixel camera using CCD technology.

Many sensors in megapixel cameras are generally similar in size as VGA sensors with a resolution of 640x480 pixels. Since a megapixel sensor contains more pixels than a VGA sensor, the size of each pixel in a megapixel sensor becomes smaller than in a VGA sensor. As a consequence, a megapixel sensor is typically less light sensitive per pixel than a VGA sensor, since the pixel size is smaller and light reflected from an object is spread to more pixels. However, technology is rapidly improving megapixel sensors, and the performance in terms of light sensitivity is constantly improving.

5. Main differences

A CMOS sensor incorporates amplifiers, A/D-converters and often circuitry for additional processing, whereas in a camera with a CCD sensor, many signal processing functions are performed outside the sensor. CMOS sensors have a lower power consumption than CCD image sensors, which means that the temperature inside the camera can be kept lower. Heat issues with CCD sensors can increase interference, but on the other hand, CMOS sensors can suffer more from structured noise.

A CMOS sensor allows 'windowing' and multi-view streaming, which cannot be performed with a CCD sensor. A CCD sensor generally has one charge-to-voltage converter per sensor, whereas a CMOS sensor has one per pixel. The faster readout from a CMOS sensor makes it easier to use for multi-megapixel cameras.

Recent technology advancements have eradicated the difference in light sensitivity between a CCD and CMOS sensor at a given price point.

6. Conclusion

CCD and CMOS sensors have different advantages, but the technology is evolving rapidly and the situation changes constantly. Hence, the best strategy for a camera manufacturer – and the one that Axis Communications adheres to – is to continually evaluate and test sensors for each and every camera that is developed. The question whether a chosen sensor is based on CCD or CMOS technology then becomes irrelevant. The only focus is if the sensor can be used to build a network camera which delivers the image quality needed and fulfills the customers' video surveillance requirements.

7. Helpful links and resources

For more information, see the following links and book:

- Axis Communications—Technical guide to network video:
- Axis Communications—Image sensors:
- Wikipedia—CMOS (Please note that Axis takes no responsibility for the contents on this website):
- Wikipedia—CCD (Please note that Axis takes no responsibility for the contents on this website):
- 'Intelligent Network Video: Understanding modern surveillance systems' by Fredrik Nilsson and Axis Communications (ISBN 1420061569)

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About Axis Communications

Axis is an IT company offering network video solutions for professional installations. The company is the global market leader in network video, driving the ongoing shift from analog to digital video surveillance. Axis products and solutions focus on security surveillance and remote monitoring, and are based on innovative, open technology platforms.

Axis is a Swedish-based company, operating worldwide with offices in more than 20 countries and cooperating with partners in more than 70 countries. Founded in 1984, Axis is listed on the NASDAQ OMX Stockholm under the ticker AXIS. For more information about Axis, please visit our website at www.axis.com

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