Rolling shutter sensors

The cost-effective alternative

An image sensor has many defining features. Since the introduction of CMOS sensors, the shutter system has surely become one of the best known of these. There are countless articles reporting on the benefits and drawbacks of shutter systems. So why another article about this topic? To date, very little light has been shed on certain aspects that are more relevant today than ever before.

Why do we make a fundamental distinction between the two modes of image capture, i.e., global shutter and rolling shutter?

1 Today's sensors

The essential difference between rolling and global shutter is the time response during the exposure phase.

With a global shutter sensor, all pixel content is cleared first in chronological order and the reset level is measured.

All of the pixels are then electronically opened to the light at the same time, marking the start of the active image capture phase. At the end of the exposure phase, the charge information is simultaneously stored in a light-insensitive area of the pixel. With CMOS sensors, this information is then converted line-by-line into gray-scale values and transferred.

The latest CMOS sensors are so fast that pixel information can be transferred serially using up to 24 lanes simultaneously. This represents an extreme challenge for the downstream circuit technology, be it FPGA, ASIC or a USB or Ethernet chipset.

Images captured with a global shutter pixel are free of any artifacts generated by movement because these are snapshots or point-in-time images.

2 Capture and read-out

The current trend of ever-increasing numbers of pixels on ever-shrinking areas calls for an extreme compromise because each pixel contains many pixel components. To make the individual pixels even smaller, for example, in order to enable two-digit megapixel resolution on a smartphone, pixel size needs to be reduced down to the 1 µm range. This is only possible by systematically omitting pixel components, such as the buffer. This means that global capture at a specific point in time is no longer possible.

The solution is to have the end of exposure determined by the direct read-out of information. The images are captured in a rolling fashion, in the sense that pixel information is transferred in sequence line by line. Hence the term "rolling shutter".

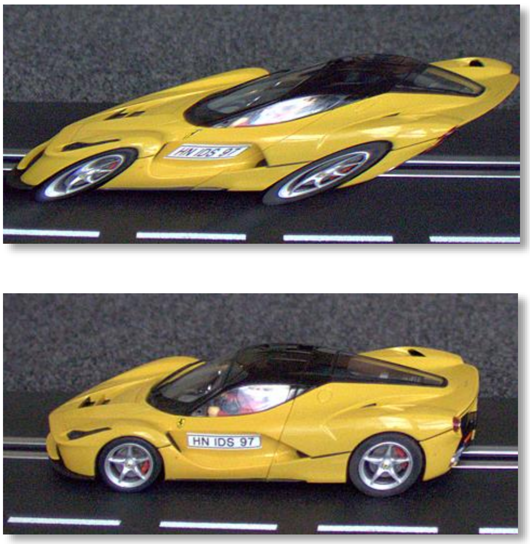
If a sensor achieves 60 images per second, the read-out and thus the exposure end time lasts 16 ms from the first line to the last. This means that exposure stops earlier in the upper portion of the image than in the bottom half. To ensure that all lines get the same exposure time, the start of exposure must also be shifted accordingly. The pixels are opened to the light line by line in sequence.

If an object moves – as, for example, in applications in intelligent transport systems (ITS) – the image is not reproduced accurately.

3 Image transfer

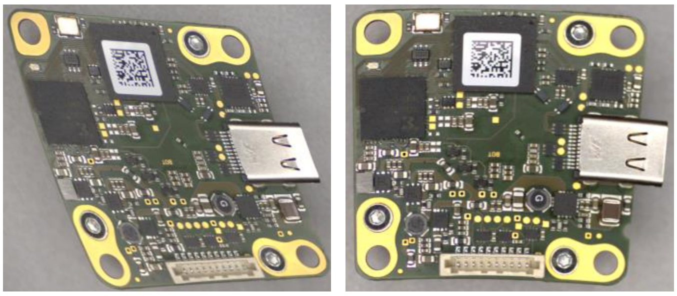
First-generation CMOS sensors had a parallel interface for the output of image data. At best, these could handle data volumes of 100 megapixels per second. For a 5 megapixel sensor, this means around 20 images per second or a read-out time of 50 ms for one image. As a result, the rolling shutter effect is clearly visible because a moving car covers a good amount of ground during this period.

Newer CMOS sensors are now five to ten times faster. And so the read-out time is very quick. The current standard is 500 megapixels per second or 120 or 240 images per second. This is largely due to new conversion technologies and electrical interfaces. The resulting 4 ms shutter time at 240 fps makes for significantly improved handling.



Comparison of shutter speed in earlier (pictured top) and the most recent (pictured bottom) rolling shutter sensors. The sign on the side of the racing car (scaled speed of a road vehicle is approx. 205 km/h) can be read and analyzed.

If the shutter's direction is the same as that of the object, virtually no obtrusive geometrical distortions are observed in the image. The use of a vertically mounted rolling shutter camera in web inspection systems has become standard practice.



Barcode recognition for moving objects rotated perpendicular to the camera produces unreadable codes (shown on the left). The solution is to rotate the camera 90°. The barcode can then be read and analyzed.

Traffic monitoring systems are commonly mounted on bridges or traffic light poles, with cameras pointing directly at the approaching objects. The same job can now also be done by cost-effective sensors for OCR or object recognition.

The same applies if the situation is reversed and there is a stationary object and a mobile camera – for example, on buses, trains or hand-held barcode scanners. Today, a more expensive global shutter sensor is often not essential for such applications.

4 Benefits of rolling shutter sensors

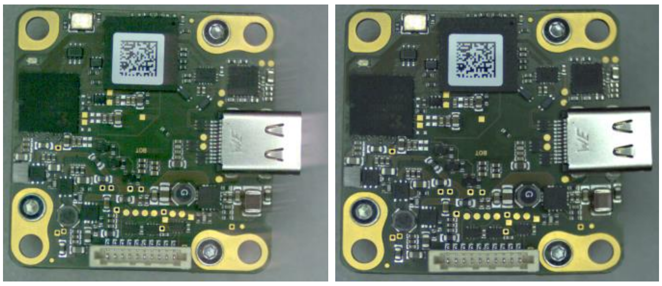
A rolling shutter sensor offers two other benefits over its global shutter counterpart.

1. Better image quality thanks to elimination of the buffer. At the end of the exposure time, the brightness value is "saved" to a memory cell in the global shutter pixel. In the latest sensors, the memory cell can store the electrons or the real voltage (already converted). Over time and with fluctuating temperatures, this stored information may deteriorate because the last line waits for the entire duration of a frame to finally be retrieved.

Depending on the design of the sensor, this may result in more frequent formation of hot pixels, as well as an increase in black level and image noise. In contrast, the rolling shutter sensor converts the brightness information directly without this intermediate step.

2. **No ghost images** A global shutter sensor can generate ghost or phantom images that distort images taken outdoors in the sunlight. That's because an extremely high level of light accompanied by a very short exposure time in the order of 10 to 30 µs represents an extreme situation for any sensor.

The information in the buffer is also indirectly exposed to the light after image capture and before read-out. Electrons from the photodiode travel here and create additional exposure. This results in ghost images, i.e., the movement of the object can also be traced as an overlay in the image after the end of the exposure time. This type of artifact doesn't occur with a rolling shutter sensor.



The image on the left shows a global shutter sensor with an extremely short exposure time and high gain. The streaking of bright points in the image is clearly visible. With the rolling shutter sensor, the image (shown on the right) is streak-free.

5 Sony STARVIS sensors

The new STARVIS series from Sony is a family of sensors that have been systematically optimized for image quality. STARVIS sensors offer extremely low noise of just 2 electrons per second. As the pixel itself has fewer components, the larger photodiode can also accumulate more charges. This high charge capacity, together with the sensor's low ambient noise, produces a very high dynamic range – one of the most important key parameter for many applications.

Another benefit of STARVIS rolling shutter sensors is the option of long time exposure. In the IDS implementation, the sensors achieve an exposure time of 120 seconds. This opens up new fields of applications, such as microscopy and analysis, where there is often little light available, necessitating a long exposure time. The speed at which the object is moving is generally irrelevant in this case, which makes an expensive global shutter sensor obsolete.

One common application for IDS cameras with rolling shutter sensors is in the very broad field of quality assurance. For example, the cameras can be integrated into workflows in which samples are positioned or machines are visually set up, food is subject to intensive size and quality inspections before being sorted, and surfaces are analyzed and inspected during printing and coating processes. The sensors have proven effective in other fields also, including medical, bio, science, traffic, kiosks, reading and detection.

6 Summary

The IMX178 and IMX290 from the Sony STARVIS series that are implemented in various industrial cameras from IDS with USB 3.0, USB 3.1 Gen.1 and GigE interfaces enable very high-quality solutions, ideal for medium- to high-volume, price-sensitive projects. In particular when used in combination with our USB 3.1 Gen 1 uEye LE board-level cameras, they offer diverse options that can be customized for your individual applications – you can, for example, choose between an M12, C-/CS mount or bare board variant.

Camera model (USB)	UI-3860CP UI-3860LE	UI-3880CP UI-3880LE
Sensor	Sony IMX290 (2.12 MP)	Sony IMX178 (6.41 MP)
SNR	40.5 dB/ 6.7 bit	41.2 dB/ 6.8 bit
QE @ 533 nm	78%	72%
Linearity error	0.04%	0.18%
Dynamics	70.5 dB/ 11.7 bit	71.3 dB/ 11.8 bit
Dark noise	2.7e-/s	2.9e-/s

The EMVA 1288 measurements testify to the exceptional features of the IDS camera with Sony STARVIS sensors.

For more information about camera models with rolling shutter sensors, visit www.ids-imaging.com or contact our sales team.

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